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Silurian biostratigraphy of the Cadia area, South of Orange, New South Wales

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Abstract

New Silurian fossil discoveries in the vicinity of Cadi a Mine indicate ages younger than shown on recent maps. Limestone, intersected in drill core immediately above an unconformable contact with Late Ordovician volcanics of the mine sequence, yielded an early Wenlock conodont fauna including Prerospathodus amorphognathoides. P procerus and P. rhodesi, together with Kockelella ramdiformis. A diverse shelly fauna of late Wenlock to early Ludlow aspect, dominated by brachio pods, is present in a slumped mudstone on the mine access road. South of the mine, in Rodds Creek valley, Silurian rocks are shown to occur as infaulted slices along the Werribee Fault. Limestone pods in this area conta in conodonts (Coryssognatlzus dubius) indicative of a Ludlow age; a graptolite fauna from nearby siltstones inc ludes Monograptus flemingii warreni. M. flexilis, Monoclimacis flwnendosaeflumendosae and Cyrrograptus ex. gr. C. rigidus, and is assigned to the lundgreni· testis Biozone (late We nlock). The youngest graptolite assemblage (Pi'fdolf) occurs in siltstones, tentatively correlated with the Wa llace Shale, exposed in a shallow excavation east of Cadia Mine. Th is fauna, which inc ludes Dictyonema sherrardae mumbilens is, Acanthograpllts aculeaws neureaens is, Pris tiograptus shearsbyi, P cf. P. dubius, Mc nograptus parultimus minutus, M. microdon aksajensis and M. cf. M. yassensis, is younger than all known graptolite faunas from the nearby Four Mile Creek area, and provides the first Australian record of Monograpllls microd on.

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Silurian Biostratigraphy of the Cadia Area, South of Orange, New South Wales

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New Silurian fossil discoveries in the vicinity of Cadia Mine indicate ages younger than shown on recent maps. Limestone, intersected in drill core immediately above an unconformable contact with Late Ordovician volcanics of the mine sequence, yielded an early Wenlock conodont fauna including *Pterospathodus amorphognathoides*, *P. procerus* and *P. rhodesi*, together with *Kockelella ranuliformis*. A diverse shelly fauna of late Wenlock to early Ludlow aspect, dominated by brachiopods, is present in a slumped mudstone on the mine access road. South of the mine, in Rodds Creek valley, Silurian rocks are shown to occur as infaulted slices along the Werribee Fault. Limestone pods in this area contain conodonts (*Coryssognathus dubius*) indicative of a Ludlow age; a graptolite fauna from nearby siltstones includes *Monograptus flemingii warreni*, *M. flexilis*, *Monoclimacis flumendosae flumendosae* and *Cyrtograptus* ex. gr. *C. rigidus*, and is assigned to the *lundgreni-testis* Biozone (late Wenlock). The youngest graptolite assemblage (Přídolí) occurs in siltstones, tentatively correlated with the Wallace Shale, exposed in a shallow excavation east of Cadia Mine. This fauna, which includes *Dictyonema sherrardae mumbilensis*, *Acanthograptus aculeatus neureaensis*, *Pristiograptus shearsbyi*, *P.* cf. *P. dubius*, *Monograptus parultimus minutus*, *M. microdon aksajensis* and *M.* cf. *M. yassensis*, is younger than all known graptolite faunas from the nearby Four Mile Creek area, and provides the first Australian record of *Monograptus microdon*.

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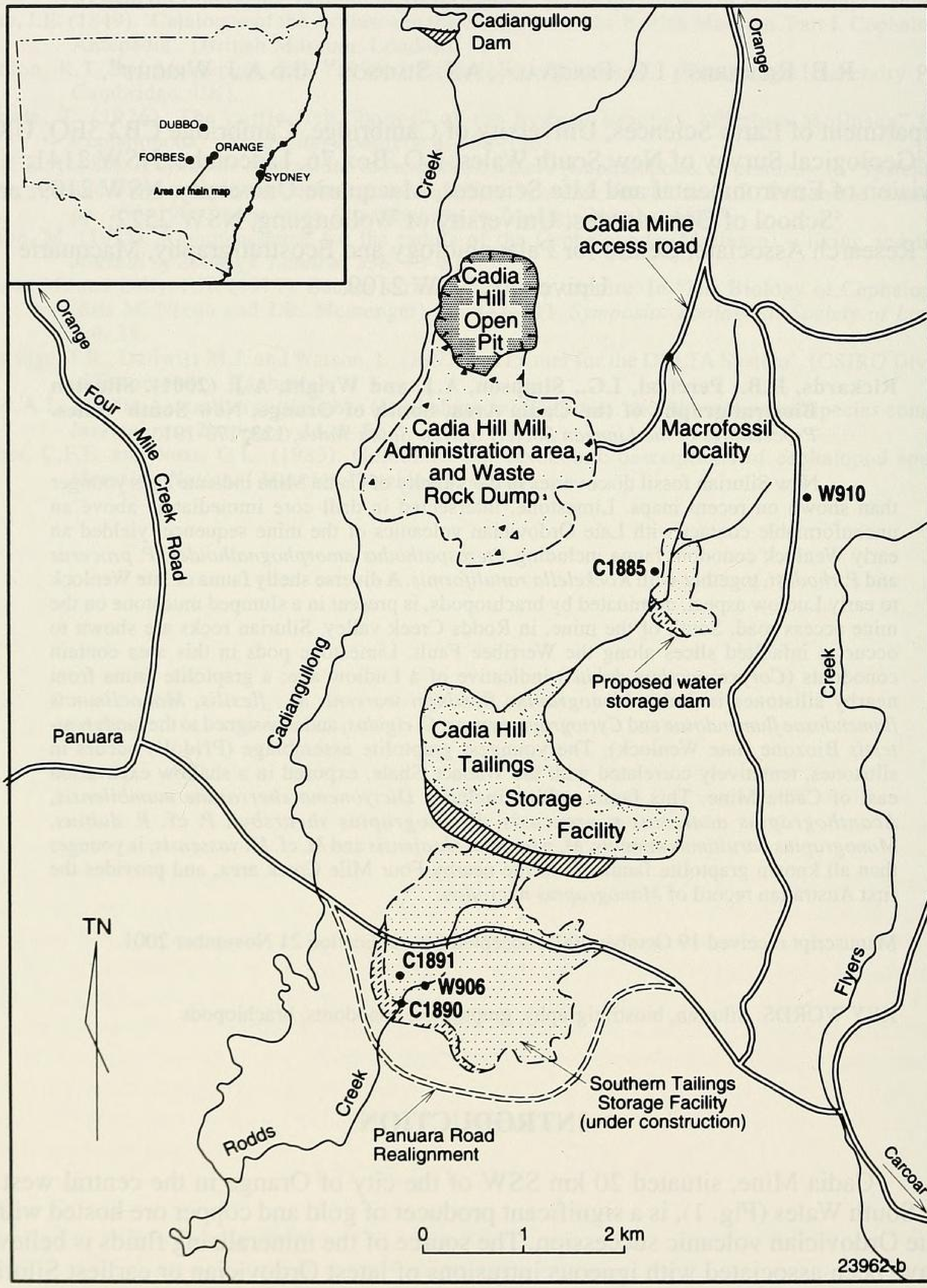
KEY WORDS: Silurian, biostratigraphy, graptolites, conodonts, brachiopods

INTRODUCTION

Cadia Mine, situated 20 km SSW of the city of Orange in the central west of New South Wales (Fig. 1), is a significant producer of gold and copper ore hosted within a Late Ordovician volcanic succession. The source of the mineralising fluids is believed to have been associated with igneous intrusions of latest Ordovician or earliest Silurian age. Overlying Silurian strata are not mineralised and, therefore, have received less attention from geologists, other than in thesis studies and regional mapping projects. Until recently, Silurian sedimentary rocks overlying the mine sequence were assumed to belong to the Cadia Coach Shale, of early-middle Llandovery age (Jenkins 1978), and

Figure 1. Locality map covering 8630-N Canowindra 1:50 000 (NE corner) and Millthorpe 8731-3-S 1:25 000 (SE corner) topographic sheets, prepared from an aerial photograph of the Cadia mine area supplied by Newcrest Mining Ltd, showing positions of palaeontological sample sites C1885, C1890, C1891, W906, W910, and macrofossil locality on mine access road.



were mapped as such by Krynen et al. (1997). Few, if any, fossil localities were known in the vicinity of the mine to confirm this age determination. Offenberg (1963) in an unpublished thesis, reported a *triangulatus* graptolite fauna (early-middle Llandovery age) from the upper reaches of Rodds Creek, and a *testis* graptolite fauna (late Wenlock) from a tributary of Cadiangullong Creek. None of this material has been located for verification, and in particular the early-middle Llandovery age assemblage appears anomalous in the light of our recent discoveries. An alternative interpretation (G.H. Packham, pers. comm.) is that the supposed *triangulatus* forms are fragments of *Cyrtograptus*, similar to those described by Rickards et al. (1995) from strata of Ludlow age in the Quarry Creek area, south of Orange. Bischoff (1986, 1997, 1998) determined conodonts from limestone in core, from a hole drilled by Pacific Copper (the previous leaseholder of the mine site during the 1970s) near Cadia Quarry, as latest Llandovery; he assigned them to the *Pterospathodus amorphognathoides —P. rhodesi* Assemblage Zone (Jeppsson 1997; Bischoff 1998). On the basis of this age, Packham et al. (1999) correlated the Silurian limestone in subcrop at Cadia with units at the top of the Waugoola Group, such as the Glendalough Formation and the Boree Creek Formation.

New palaeontological data derived from localities made known to us by geologists from Newcrest Mining Limited, operator of the Cadia Mine, has enabled us in the current paper to (1) recognise the existence of Silurian rocks where these were previously unknown, and (2) to demonstrate that outcrops mapped as Early Silurian Ashburnia Group on the second edition Bathurst 1:250 000 Geological Map (Raymond, Pogson et al. 1998) are in fact much younger, some possibly correlative with the Wallace Shale of Přídolí age. It should be noted here that stratigraphic terminology applied to the Silurian strata of the region has not yet stabilised; various schemes have been proposed by Jenkins (1978), and in the Explanatory Notes to the second edition Bathurst geological map (Pogson and Watkins 1998). Our aim in documenting faunas from new fossil localities around Cadia is to increase biostratigraphic precision, allowing more confident correlation with those areas where the stratigraphic succession is well established. It is not the intention of this contribution to revise the geological mapping of exposures in the vicinity of Cadia Mine, as most of the area is held under exploration leasehold; although it has been mapped in considerable detail by company geologists, this information remains confidential.

Added impetus was given to this project by imminent extensions to the minesite infrastructure, which will entail several of the localities studied herein becoming inaccessible. Those in the lower valley of Rodds Creek will shortly be submerged beneath a southern extension of the Cadia Hill tailings storage facility, while the site of drill hole STRC 198 is located adjacent to a planned water holding dam SE of the Cadia Mine. Exploration geologists from Newcrest Ltd facilitated access to these sites and samples, prior to commencement of earthworks associated with these projects (outlined on Fig. 1).

Rickards and Wright studied the graptolite faunas documented herein as part of a larger project being undertaken with Dr Gordon Packham on the Silurian graptolites of the nearby Four Mile Creek area. The limestone samples were processed for conodonts at the Lidcombe laboratory of the NSW Department of Mineral Resources, and their age implications were analysed by Simpson and Percival. The brachiopods were studied by Percival.

Grid references (GR) quoted in the text refer to AMG co-ordinates on the Canowindra 8630–N 1:50 000 and Millthorpe 8731-3-S 1:25 000 topographic sheets, and were determined in the field using a hand-held GPS unit. Locality numbers prefixed by C indicate Geological Survey of NSW microfossil collections (figured conodonts designated MMMC), and those prefixed by W are University of Wollongong localities. Illustrated macrofossils are catalogued either in collections of the Australian Museum, Sydney (prefix AMF), or in the Geological Survey of NSW palaeontology collection (specimens denoted MMF) housed at Lidcombe, NSW.

GEOLOGICAL CONTEXT OF NEW FOSSIL DISCOVERIES

Recent drilling by Newcrest Mining Limited in the upper reaches of Rodds Creek, about 2.5 km SE of the Cadia Hill mine mill (Fig. 1), intersected limestone 2 m above an unconformity with the Late Ordovician volcanics forming the mine sequence. Limestone chips from the reverse circulation hole STRC 198 were processed using standard acetic acid dissolution techniques, and yielded a diverse earliest Wenlock conodont assemblage (C1885), further discussed below. The significance of this discovery is that for the first time in the Cadia area, an age-diagnostic Silurian fauna has been accurately located with respect to the Ordovician succession. The age of the latter at Cadia is known to be middle Late Ordovician, specifically late Eastonian (Ea3) (Packham et al. 1999). Elsewhere in the nearby region, in the valley of the Belubula River to the south, the youngest Ordovician unit (Angullong Formation) contains late Late Ordovician graptolites (middle Bolindian, no younger than Bo3) (Jenkins 1978). The stratigraphic break between the top of the Ordovician volcanics and the base of the Silurian limestone in drill hole STRC 198 corresponds to the interval of igneous intrusions (isotopically dated at about 446 Ma – see Packham et al. 1999:8) which are believed responsible for introduction of the mineralisation to the Cadia area, prior to resumption of sedimentation in the Silurian.

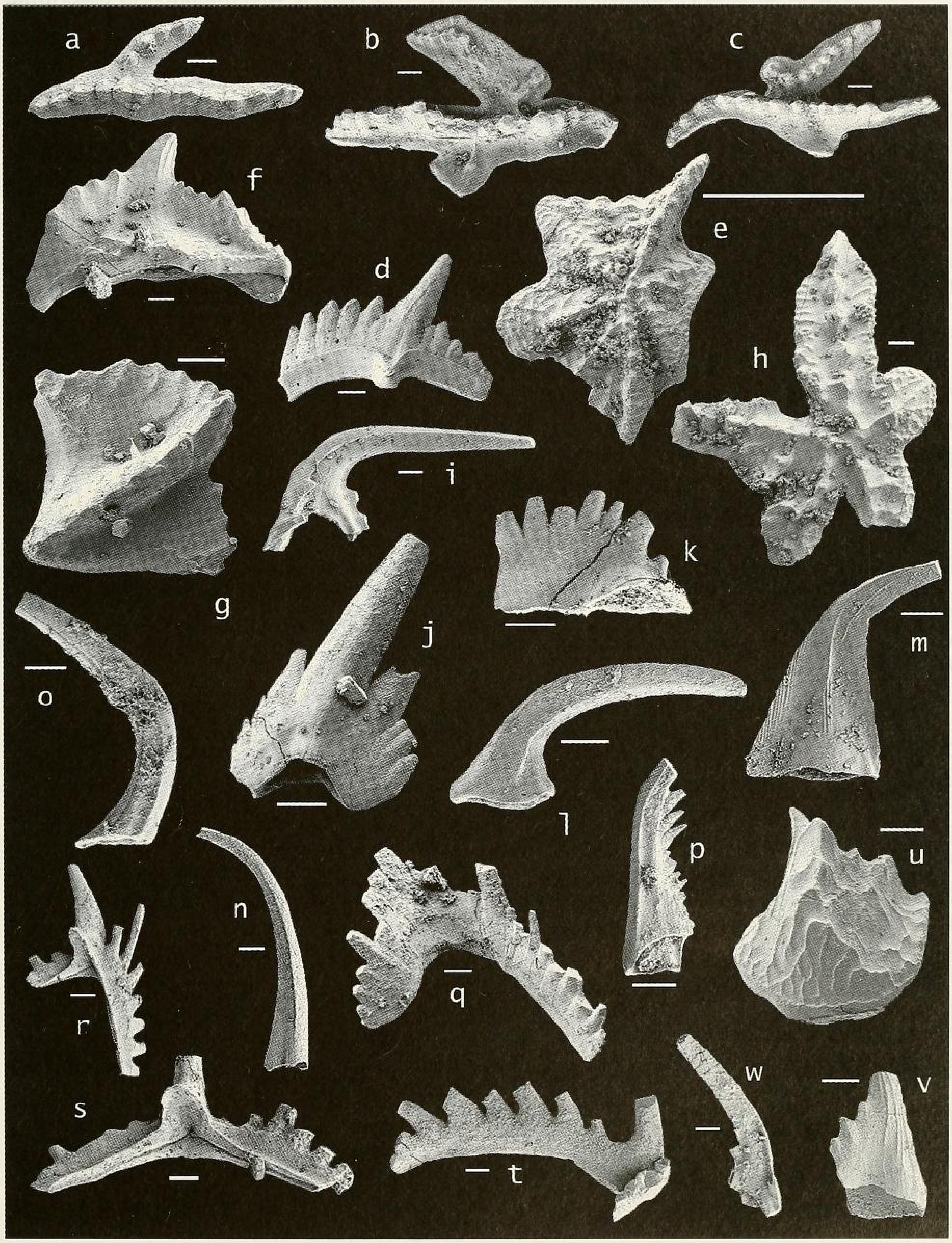
Nearby in the valley of Rodds Creek, south of the present Carcoar-Panuara road (Fig. 1), an area adjacent to the Wongalong Fault had previously been mapped as Angullong Formation (formerly Angullong Tuff) by Smith (1966). More recently, the major structural feature through the region has been renamed the Werribee Fault, separating two blocks characterised by different facies of the Middle to Late Ordovician Weemalla Formation (Raymond, Pogson et al. 1998). An isolated limestone pod containing halysitid and favositid corals, which had been mapped as part of the Angullong Tuff by Smith (1966), was reassessed by Jenkins (1978:122) who identified *Halysites* aff. *H. amplitubata* Lambe (form B) from this locality. Jenkins noted that this species also occurred in the Cobblers Creek Limestone at the base of the Waugoola Group, of late Llandovery age. This limestone pod was sampled for conodonts (locality C1890) and yielded one element of *Coryssognathus dubius*; this species has a range from late Llandovery to early Přídolí, but is locally restricted to the Ludlow.

The limestone pod is at the southern end of a fault slice of Silurian sediments within the Weemalla Formation on the Werribee Fault. About 250 m upstream from the limestone, late Wenlock graptolites, correlated with the *lundgreni-testis* Biozone, are present in black siltstones in the west bank of Rodds Creek (locality W906). The age of this assemblage, discussed below, suggests that the probable Ludlow age inferred for C1890 is not unrealistic. Another, smaller, limestone pod was sampled for conodonts (GSNSW locality C1891) in a tributary gully of the main creek, but the small assemblage of fragmentary and poorly preserved elements included no age-diagnostic forms.

Brachiopods and other shelly fauna are preserved in a mudstone on the main Cadia mine access road at GR 687250 6295000. All shells are disarticulated, and many other fossils are fragmentary, indicative of slumping of the horizon into deeper water; sedimentary structures confirm this interpretation. Very rare well-rounded pebbles are present, but the lithology is predominantly a grey to white fine silt to mud lithology, weathering brown. The fossils are scattered throughout the rock, but are occasionally concentrated in parallel layers. Several of the brachiopods found at this site are similar to those previously described from the late Wenlock Panuara Formation of the Spring and Quarry Creek area, west of Orange.

The youngest Silurian strata in the Cadia area have been recognised in a road gravel pit (locality W910), adjacent to the road through the forest east of the mine access road. Here, loose blocks on the quarry floor yielded very rare shelly

Figure 2. SEM photographs of Silurian conodonts from locality C1885 (a-v) and C1890 (w); **a**, Pa element of *Pterospathodus procerus*, MMMC 2565; **b**, Pa element of *Pterospathodus rhodesi*, MMMC 2566; **c**, **d**, Pa and Pb elements of *Pterospathodus amorphognathoides*, MMMC 2567, 2568; **e**, **f**, **g**, Pa, Pb and Sa elements of *Apsidognathus tuberculatus*, MMMC 2569, 2570, 2571; **h**, **i**, Pa and Sc elements of *Distomodus staurognathoides*, MMMC 2572, 2573; **j**, *Carniodus carnulus*, MMMC 2574; **k**, Pa element of *Kockelella ranuliformis*, MMMC 2575; **l**, **m**, *Ansella mischa*, MMMC 2576, 2577; **n**, *Panderodus unicostatus*, MMMC 2578; **o**, *Panderodus recurvatus*, MMMC 2579; **p**, *Pseudobelodella* sp., MMMC 2580; **q**, **r**, Pb and Sa elements of *Pseudolonchodina* (*Aspelundia*) *borenorensis*, MMMC 2581, 2582; **s**, **t**, Sa and Sc elements of *Oulodus rectangularis*, MMMC 2583, 2584; **u**, *Pyrsognathus latus*, MMMC 2585; **v**, *Pyrsognathus obliquus*, MMMC 2586; **w**, Sb element of *Coryssognathus dubius*, MMMC 2587; each scale bar represents 100 microns.



fossils (brachiopod *Skenidioides*; indeterminate coral), associated with graptolites of Přídolí age. This age is younger than that of all known graptolite faunas from the Four Mile Creek area to the west of Cadia, where rich Llandovery to Ludlow graptolite faunas have been known since the work of Stevens and Packham (1953).

NEW OCCURRENCES OF SILURIAN CONODONTS [AJS and IGP]

Limestone from Newcrest drillhole STRC 198 (locality C1885)

The drilling site, located at GR 686829E 6293159N, was intended to determine sub-surface geology in the vicinity of a proposed extension of the mine water reservoir. The cuttings were logged by N. Swingler for Newcrest Exploration. After intersecting a feldspathic siltstone from surface to 19 m, followed by 12 m of calcareous arkose, and a further thick succession of feldspathic siltstone, chips of a pink-grey pyritic limestone were recovered from a depth interval of 79-87 m. The lower limit corresponds to a depth 2 m above the contact with lithic volcaniclastic breccia referred to the Ordovician Forest Reefs Volcanics; the intervening 2 m is composed of calcareous grit, according to the well log.

Conodonts extracted from the limestone sample of 2.7 kg (Fig. 2) were identified as: *Ansella mischa*, *Apsidognathus tuberculatus*, *Carniodus carnulus*, *Distomodus staurognathoides*, *Kockelella ranuliformis*, *Oulodus rectangularis*, *Panderodus unicostatus*, *P. recurvatus*, *Pseudobelodella* sp., *Pseudolonchodina (Aspelundia) borenorensis* (= *Oulodus planus borenorensis* Bischoff, 1986), a single specimen of *Pseudooneotodus tricornis*, *Pterospathodus amorphognathoides*, *Pt. procerus*, *Pt. rhodesi*, *Pyrsognathus latus* and *Py. obliquus*. Presence of the three species of *Pterospathodus* places the assemblage within the late Llandovery to early Wenlock *amorphognathoides* Assemblage Zone. Additionally, elements of *Panderodus recurvatus* are identical with those attributed to the *amorphognathoides* Zone by Jeppsson (1997:Fig 7.5). Many of the species recognised from C1885 also occur in the Quarry Creek Limestone and Boree Creek Formation (Bischoff 1986,1997; Cockle 1999) and correlative units elsewhere in the central west of NSW.

This conodont assemblage also has many species in common with that documented by Bischoff (1986) from drillhole PC402 at Cadia, with two important exceptions. The occurrence of a single broken specimen of *Kockelella ranuliformis* in C1885 (Fig. 2k) suggests an age for this sample of earliest Wenlock, rather than late Llandovery as determined by Bischoff (1986) for the limestone intersected in PC402. Although *K. ranuliformis* is found in great numbers during the Wenlock *ranuliformis* Zone, its first appearance precedes the base of this zone (Barrick and Klapper 1976). Earliest known occurrences of *K. ranuliformis* include Llandovery examples from Great Britain (Aldridge 1985) and Greenland (Armstrong 1990). However, *K. ranuliformis* was never recovered from Llandovery strata in Bischoff's (1986) extensive documentation of Early Silurian conodont faunas from NSW. Its occurrence with species of *Pterospathodus* in C1885, therefore, permits a very narrow age diagnosis of earliest Wenlock, near the close of the *amorphognathoides* Zone. The presence of *Pseudooneotodus tricornis* is also in accord with this restricted time interval, although rare examples from the Llandovery *celloni* Zone are known (Bischoff 1986:Text-fig. 10).

Bischoff (1986:35) favoured an early age within the *amorphognathoides* Zone (i.e. late Llandovery) for PC402 based on the occurrence of *Ozarkodina cadiaensis*. This species, however, is poorly known and probably ecologically constrained (Simpson and Talent 1995:142). The late Llandovery age for this species seems to be based on one single occurrence of the species from low in the Boree Creek Formation (sample B5, Bischoff 1986:Table 10). Simpson (1995) pointed out that there are some difficulties with interpreting the position of the lower boundary of the *amorphognathoides* Zone within the Boree Creek sequence. *Ozarkodina cadiaensis* has also been recovered from the Lobelia Limestone in the Limestone Creek region of eastern Victoria (Simpson and

Talent 1995), for which a generalised late Llandovery to Early Wenlock age (*celloni* to *amorphognathoides* zones) has been inferred. Absence of *Ozarkodina cadiaensis* from the fauna of C1885 could be interpreted as indirect evidence in support of a slightly younger age than that of PC402, although caution would be advised in view of possible ecologic constraints and uncertainties concerning the full range of this taxon.

Limestone pod in Rodds Creek (locality C1890)

It is not clear whether the isolated limestone outcrop at GR 684437E 6288532N, previously recognised by Jenkins (1978) as being of probable late Llandovery age on the basis of a halysitid coral similar to a species from the Cobblers Creek Limestone (see above), is allochthonous or autochthonous. Other macrofossils present, including favositid corals, do not assist with precise age determination. A sample weighing 8.2 kg of this limestone yielded 39 conodont elements, mostly *Panderodus*, but also including a solitary example of *Walliserodus* sp., and a single ramiform element of *Coryssognathus dubius* (Fig. 2w). The latter species implies a probable Ludlow age for the limestone, based on other Eastern Australian occurrences (Link and Druce 1972; Simpson et al. 1993; Simpson and Talent 1995; Cockle 1999; Talent and Mawson 1999), although the species is elsewhere reported to range from late Llandovery to early Přídolí (Miller and Aldridge 1993). The relative abundance of coniform conodont elements is not usually a feature of Early Silurian faunas. The microfossil assemblage is dominated by abundant smooth ostracodes, whose identity has not been determined.

Limestone pod in Rodds Creek valley (locality C1891)

A separate limestone lens at GR 684354E 6288723N, approximately 300 m NW of the Wenlock graptolite locality W906, is surrounded by siltstones and could be allochthonous. Alternatively, given its recrystallized appearance, it may have been caught up in a faulted zone associated with the main Werribee Fault, and tectonically emplaced. Conodonts recovered from a 7 kg sample of the limestone are fragmentary, making identification tenuous. Most have surface textures suggestive of post depositional fluid movements. The fauna consists of ?*Walliserodus* sp., *Panderodus* sp., *Oulodus* sp. and *Ozarkodina* sp. Some of the fragmentary Sa and Sb elements of *Ozarkodina* sp. have a basal cavity morphology resembling that of *Ozarkodina excavata*. It is only possible to infer a very generalised Silurian to Early Devonian age for this fauna.

NEW OCCURRENCES OF SILURIAN BRACHIOPODS AND OTHER MACROFAUNA [IGP]

Fauna identified in the outcrop in the Cadia Mine access road include brachiopods *Skenidioides* sp., an indeterminate orthoidean, *Plectodonta*? sp., *Lissatrypa*? sp., *Atrypoidea* cf. *A. australis*, an indeterminate plectatrypid, *Coelospira*? sp., *Nucleospira*? sp., and an indeterminate pentamerid; fragments of phacopid and calymenid? trilobites; graptolites (exceptionally rare); bivalves; ostracodes; crinoid ossicles; bryozoa; an indeterminate solitary rugose coral; and an indeterminate stromatoporoid. Selected representatives of this assemblage are illustrated in Fig. 3. Given the fact that virtually all the fauna at this locality is fragmented or disarticulated, having been preserved in a large-scale mud slump, identifications are necessarily provisional; their confirmation will entail much more extensive collections from the site.

All of the brachiopods are represented by isolated valves. Several genera described by Strusz (1982) from the late Wenlock Walker Volcanics of the Canberra area are probably present at the Cadia Mine access road site, including *Skenidioides*, *Lissatrypa*? (as *Australina*), *Coelospira*?, and *Nucleospira*?. *Skenidioides* is a long-ranging form which also occurs in the road base quarry adjacent to Cadia Road (locality W910, discussed below); there it is associated with graptolites of Přídolí age. It is impossible to say whether the solitary specimens known from each locality represent the same, or different, species. A specimen of *Plectodonta* (Fig. 3m-n herein) is possibly comparable to material described as the new species *P. brownae* by Rickards and Wright (1997a) from a late Wenlock horizon in the Panuara Formation at nearby Cobblers Creek, 3 km SW of Panuara (Fig. 1); generic attribution of the specimen from the Cadia Mine road site is uncertain due to lack of the dorsal valve, and apparent absence (due to preservation) of hingeline denticulation. Rickards and Wright (1997a) also recorded *Lissatrypa*? sp. at Cobblers Creek, suggesting another potential similarity with the Cadia Mine access road assemblage which has yielded a fragmentary ventral and complete dorsal valve (Fig. 3q-r). denticulation. Rickards and Wright (1997a) also recorded *Lissatrypa*? sp. at Cobblers Creek, suggesting another potential similarity with the Cadia Mine access road assemblage which has yielded a fragmentary ventral and complete dorsal valve (Fig. 3q-r).

The solitary dorsal valve referred to *Atrypoidea* cf. *A. australis* clearly displays dorsomedially-directed spiralia (Fig. 3h) and the characteristic smooth exterior (with closely spaced concentric growth rings) of the lissatrypinids (Fig. 3i). Several fragments of shells showing identical spiralia were recognised in the fauna. *Atrypoidea australis*, originally described from the Molong Limestone, north of Orange, by Mitchell and Dun (1920), was revised by Copper (1977); the age of the Molong Limestone is early Ludlow (*ploeckensis* and *siluricus* Conodont Zones; J.W. Pickett, pers. comm.). Copper (1986:text-fig. 18) showed the range of *Atrypoidea* extending downwards into the late Wenlock.

Also present in the assemblage are incomplete specimens of graptolites (Fig. 3a-b, c) identified as *Monograptus* sensu stricto. Although the available material does not permit species to be determined, these suggest an age no older than late Llandovery.

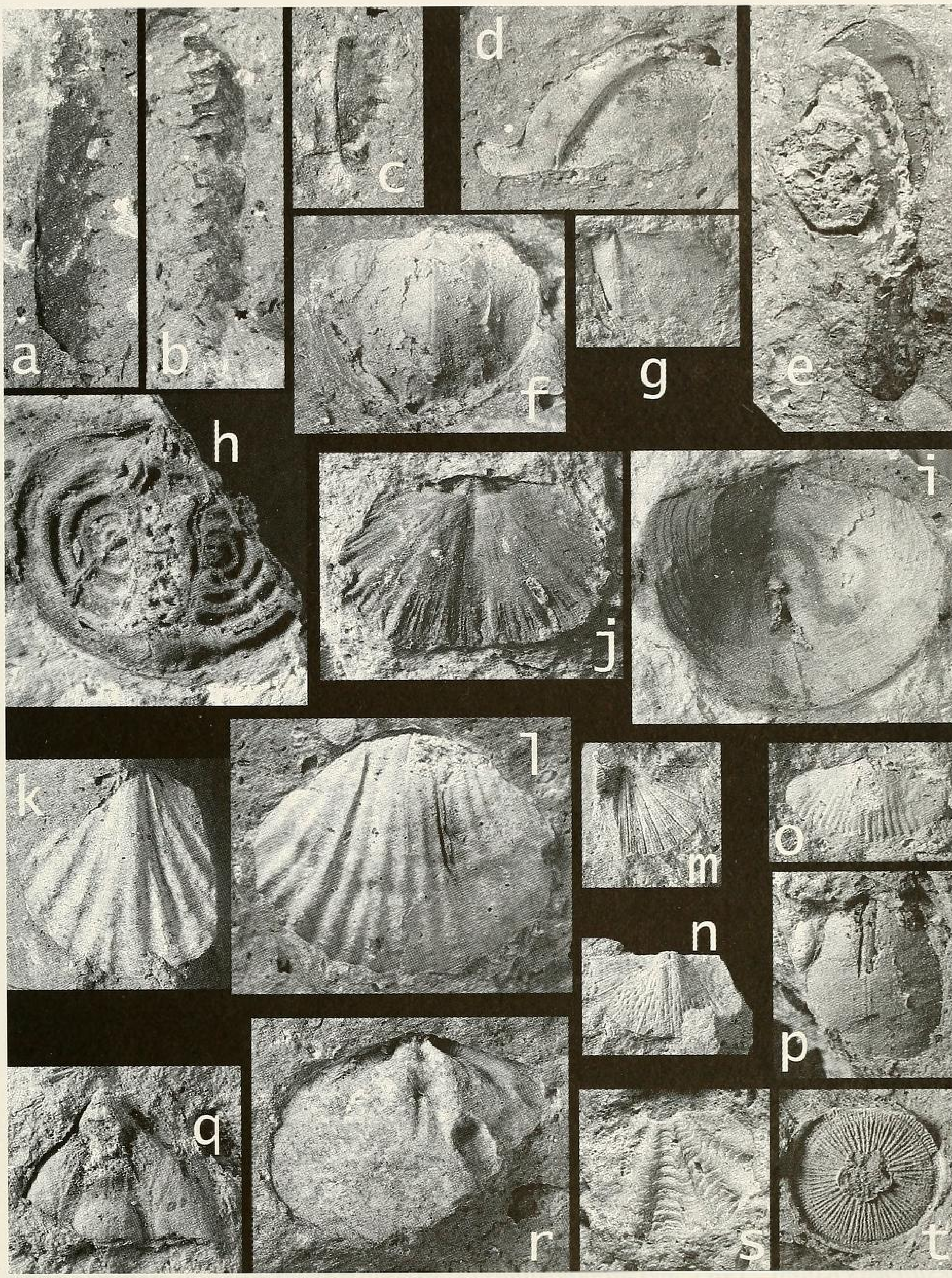
NEW OCCURRENCES OF SILURIAN GRAPTOLITES [RBR and AJW]

Rodds Creek Fauna: Age and Significance

A low-diversity Wenlock graptolite fauna was unexpectedly obtained from the west bank of Rodds Creek at GR 684682E 6288609N. The area which includes the Rodds Creek fossil locality was studied by Smith (1966). The graptolite locality W906 is located in the immediate vicinity of the Werribee Fault (Fig. 1) which separates two masses of Ordovician strata. It was not until the graptolites were collected that the presence of Silurian strata in fault slices was recognised. The occurrence of a Wenlock fauna in beds emplaced along the Werribee Fault places a maximum age on the northern segment of that fault. Fifteen kilometres to the SW, between the villages of Lyndhurst and Woodstock, the same fault offsets Ordovician strata against Canowindra Volcanics; the latter unit is palaeontologically constrained and isotopically dated as of early to middle Wenlock age (Krynen and Pogson 1998).

The assemblage consists of four species of graptolites, with the only associated fossils being sponge spicules (Fig. 4H). The fauna comprises: *Monograptus flemingii*

Figure 3 (facing). Silurian macrofossils from minesite access road locality; **a**, **b**, *Monograptus* sp., counterparts MMF 36716a-b; **c**, *Monograptus* sp., MMF 36683; **d**, free cheek of calymenid trilobite, MMF 36676b; **e**, lateral fragment of cephalon of phacopid trilobite, showing large schizochroal eye (damaged), MMF 36708a; **f**, *Nucleospira*? sp., exfoliated internal mould of ventral valve, MMF 36663a; **g**, *Nucleospira*? sp, posterior fragment of ventral valve, MMF 36675; **h**, **i**, *Atrypoidea* cf. *A. australis*, composite internal mould of dorsal valve showing dorsomedially-directed spiralia, and corresponding external mould, MMF 36684a-b; **j**, indeterminate orthoidean dorsal valve internal mould, MMF 36715; **k**, *Coelospira*? sp., ventral valve external, MMF 36677a; **l**, indeterminate rhynchonellid, dorsal valve exhibiting very weak median septum, MMF 36669a; **m**, **n**, *Plectodonta*? sp., external and internal moulds of ventral valve, MMF 36701a-b; **o**, *Skenidioides* sp., ventral valve internal mould, MMF 36666a; **p**, indeterminate pentameride, internal mould of dorsal valve displaying parallel discrete brachial plates, MMF 36697; **q**, **r**, *Lissatrypa*? sp., posterior fragment of ventral valve internal mould, MMF 36662a, and internal mould of dorsal valve, MMF 36712; **s**, external mould of indeterminate plectatrypid, showing strong growth lamellae, MMF 36711; **t**, cross section of crinoid ossicle, MMF 36694. Magnification of all specimens x4, except for j, l, r all x3.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Salter, 1852 *warreni* Burns and Rickards, 1993; *Monograptus flexilis* Wood, 1900 s. l.; *Monoclimacis flumendosae flumendosae* (Gortani, 1922); and *Cyrtograptus* ex gr. *rigidus* Tullberg, 1883.

Two species, *Cyrtograptus* ex. gr. *rigidus* (Fig. 4H) and *M. flexilis* s. l. (Fig. 4C), are each represented in this fauna by only one specimen (plus counterpart). *Monograptus flemingii warreni* is known from five specimens (Figs 4A-B), and *Monoclimacis f. flumendosae* (Figs 4D-G) is represented by about one hundred specimens. The last, a cosmopolitan species, closely resembles material from various parts of the world, and is especially well preserved in our collection, showing (for example) the base of the interthecal septum very clearly as a thickened black rod (Figs 4D-G). Without a definite cladium and more specimens, the *Cyrtograptus* is difficult to identify to species, but it does seem to be too robust for *C. ellesae* and *C. hamatus;* however, the proximal regions of some late Wenlock cyrtograptids (except for *C. lundgreni* and *C. pseudolundgreni)* are poorly known so our specimen may be referable to one of these forms. A peculiar feature of the assemblage is the absence of *Pristiograptus dubius* (Suess, 1851), normally a common species in Wenlock assemblages above the middle *riccartonensis* Biozone (though sometimes uncommon in the *lundgreni-testis* Biozone).

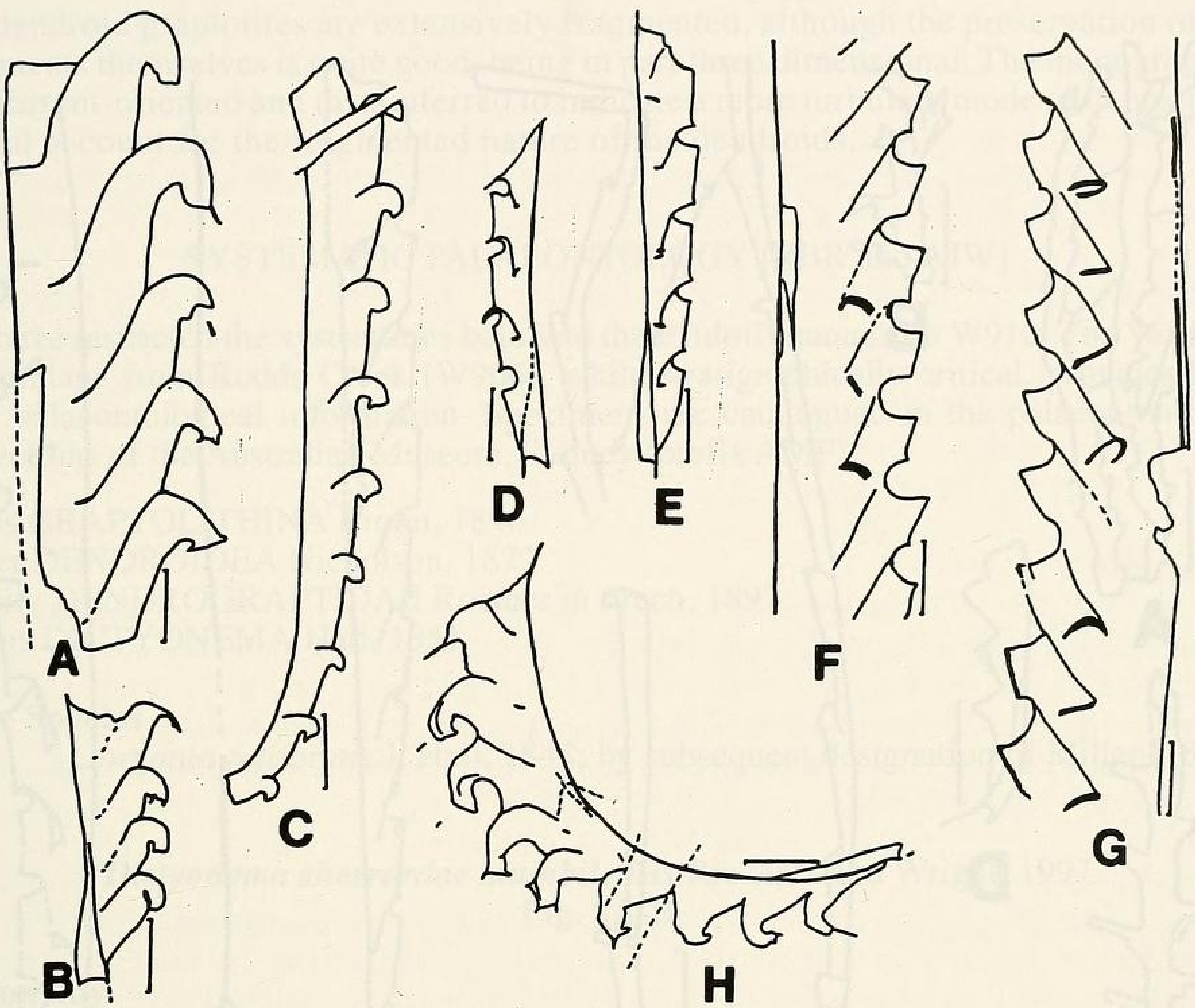
Monograptus f. warreni was recorded from Quarry Creek by Rickards et al. (1995); its full range is probably not yet established, but available records suggest roughly the *lundgreni-testis* Biozone. *Monograptus flexilis* has a longer range, appearing in the *rigidus* Biozone and ranging up into the lower parts of the *lundgreni-testis* Biozone. *Monoclimacis f. flumendosae* ranges from the upper part of the *riccartonensis* Biozone through most of the *lundgreni-testis* Biozone. From these three species, the inferred age is the *lundgreni-testis* Biozone, the penultimate Wenlock zone. However, *Cyrtograptus* ex. gr. *rigidus* does not range up into the *lundgreni-testis* Biozone, being typical of the *rigidus* to *ellesae* biozones; the single specimen from Rodds Creek may have the beginnings of a cladium on th5 (Fig. 4H) which suggests a form close to *C. rigidus s.s.* The best age that can be inferred for the fauna is middle to late Wenlock, most probably in the early part of the *lundgreni-testis* Biozone. It should be noted that the ranges of Silurian graptolites occurring in the Spring-Quarry Creek, Four Mile Creek and Cheesemans Creek sequences in the Orange region are not fully established, so that this age assignment, based on non-Australian data, may be inaccurate.

W910 Fauna: Age and Significance

This fauna was collected from bulldozed blocks in a small quarry for road gravel (GR 688584E 6294138N) on the E side of Cadia Road, between the mine access turnoff and the Panuara-Carcoar Road (Fig. 1). Exposures in the vicinity of the gravel pit are poor and deeply weathered, with quarried blocks providing temporary exposures. Graptolites were extracted from laminated lithologies and fragmental brachiopods from brecciated blocks.

The assemblage is: *Dictyonema sherrardae mumbilensis* Rickards and Wright, 1997; *Acanthograptus aculeatus neureaensis* Rickards and Wright, 1997; *Pristiograptus shearsbyi* Rickards and Wright, 1999; *Pristiograptus* cf. *dubius* (Suess, 1851); *Monograptus parultimus minutus* Rickards et al., 1998; *Monograptus microdon aksajensis* Koren', 1983; and *Monograptus* cf. *yassensis* (Rickards and Wright, 1999). The two dendroids have been recorded previously only from the late Ludlow (*inexpectatus* to *kozlowskii* biozones) of the Barnby Hills Shale (Rickards and Wright 1997b). *P. shearsbyi* has been recorded from the late Ludlow (*praecornutus* Biozone) into the late Přídolí (Rickards and Wright 1999:Fig 2). The only previous record of *M. parultimus minutus* is from a monotypic assemblage in the Willow Glen Formation of the Cudgegong district, NSW, which Rickards et al. (1998) considered probably of Přídolí age; however, we have identified this subspecies in collections from Bungonia with *Bohemograptus bohemicus tenuis*, from what are taken to be late

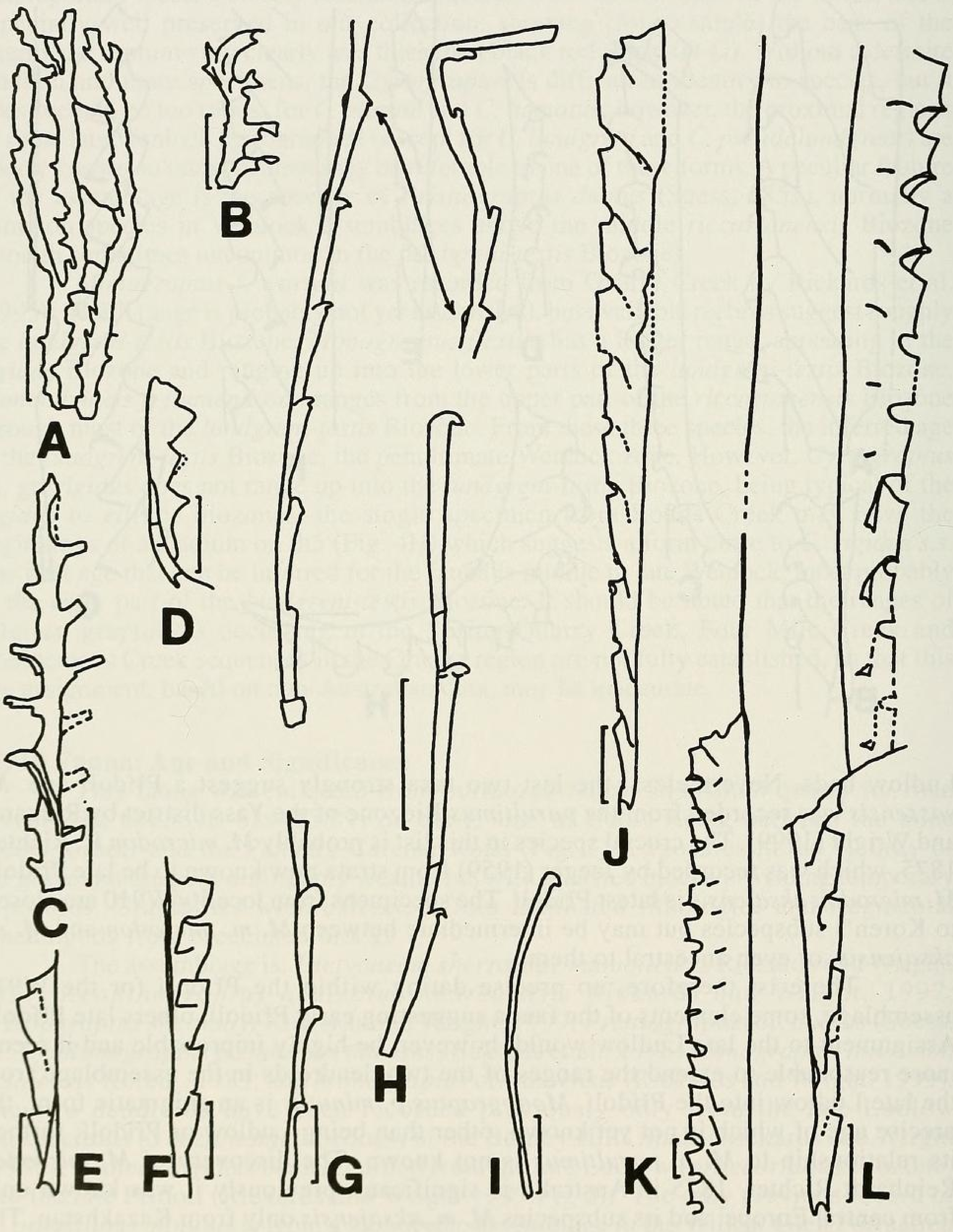
Figure 4. **A-H,** Wenlock graptolites from locality W906. **A-B**, *Monograptus flemingii warreni* Burns and Rickards, 1993, respectively AMF 114862, AMF 114863, proximal and distal parts, the latter showing lateral apertural processes. **C**, *Monograptus flexilis* Wood, AMF 114866, a poorly preserved specimen lacking the extreme proximal end. **D-G**, *Monoclimacis flumendosae flumendosae* (Gortani), respectively two proximal ends AMF 114861, AMF 114864, and two distal fragments AMF 114860, AMF 114865, the last showing the base of the interthecal septum particularly well. **H**, *Cyrtograptus* ex gr. *rigidus* Tullberg, AMF 114867. Dashed lines in this figure indicate positions of overlying sponge spicules. Scale bars 1 mm, scale approximately 10.



Ludlow beds. Nevertheless, the last two taxa strongly suggest a Přídolí age. *M. yassensis* was recorded from the *parultimus* Biozone of the Yass district by Rickards and Wright (1999). The crucial species in this list is probably *M. microdon* R. Richter, 1875, which was recorded by Jaeger (1959) from strata now known to be late Přídolí; *M. microdon aksajensis* is latest Přídolí. The specimens from locality W910 are closest to Koren's subspecies but may be intermediate between *M. m. microdon* and *M. m. aksajensis,* or even ancestral to them.

There is, therefore, no precise dating within the Přídolí for the W910 assemblage, some elements of the fauna suggesting early Přídolí, others late Přídolí. Assignment to the late Ludlow would, however, be highly improbable and it seems more reasonable to extend the ranges of the two dendroids in the assemblage from the late Ludlow into the Přídolí. *Monograptus p. minutus* is an enigmatic form, the precise age of which is not yet known, other than being Ludlow or Přídolí; further, its relationship to *M. p. parultimus* is not known. The discovery of *M. microdon* Reinhardt Richter, 1875 in Australia is significant: previously it was known only from central Europe, and its subspecies *M. m. aksajensis* only from Kazakhstan. The occurrence of the latter at W910 does suggest a later rather than earlier Přídolí age, without being unequivocal. However, the most striking record is that of *M.* cf. *yassensis*. These tiny graptolites are very difficult to see in the field, and the present

Figure 5. **A-L**, Přídolí graptolites from locality W910; **A**, **B**, *Dictyonema sherrardae mumbilensis* Rickards and Wright, respectively AMF 114795 and 114796; **C**, *Acanthograptus aculeatus neureaensis* Rickards and Wright, AMF 114638; **D**, *Monograptus parultimus minutus* Rickards *et al.*, AMF 114669; **E**, **F**, *Pristiograptus shearsbyi* Rickards and Wright, respectively AMF 114640 and 114633; **G-I**, *Monograptus* cf. *yassensis* Rickards and Wright, respectively AMF 114636, 114793 and 114639; **J-L**, *Monograptus microdon* cf. *aksajensis* Koren', respectively AMF 114632, 114637, and 114634; scale bars 1 mm.



collection was only discovered during microscopic examination of rock slabs; our original collections of such tiny forms came from the early Přídolí of the Yass district (Rickards and Wright 1999). The generic attribution of this species and *M. mitchelli* (Rickards and Wright, 1999) is very difficult. They seem not to be related to *Crinitograptus* or *Neocucullograptus* and yet there are no other small graptolites in the late Ludlow or Přídolí; both genera are much more robust than *M. yassensis.*

The W910 locality is unusual for Silurian graptolitic rocks in NSW in that the dendroid graptolites are extensively fragmented, although the preservation of the fragments themselves is quite good, being in part three dimensional. The monograptids are current-oriented and this, inferred to indicate a more turbulent mode of deposition, would account for the fragmented nature of the dendroids.

SYSTEMATIC PALAEONTOLOGY [RBR and AJW]

We have restricted the systematics below to the Přídolí fauna from W910. The Wenlock assemblage from Rodds Creek (W906), while stratigraphically critical, provides little new palaeontological information. Specimens are catalogued in the palaeontological collections of the Australian Museum, Sydney (prefix AMF).

Class GRAPTOLITHINA Bronn, 1846
Order DENDROIDEA Nicholson, 1872
Family DENDROGRAPTIDAE Roemer in Frech, 1897
Genus DICTYONEMA Hall, 1851

Type Species

Gorgonia retiformis J. Hall, 1843; by subsequent designation of Miller (1889).

Dictyonema sherrardae mumbilensis Rickards and Wright, 1997
Fig. 5A-B

Synonymy

1997b *Dictyonema sherrardae mumbilensis* subsp. nov.; Rickards and Wright, pp. 215-216, fig. 6D.

Description

Dictyonema with aperturally isolated autothecal apertures in which the dorsal process extends as a small plate; autothecal spacing 25+ in 10 mm; dorsoventral width 0.70-80 mm; lateral stipe width 0.20 mm; stipe spacing approximately 8 in 10 mm; dissepimental spacing about 12 in 10 mm.

Material

Several fragmentary specimens, AMF 114795-6 from locality W910.

Remarks

Although available specimens are very fragmentary, the diagnostic features of the species are recognisable and measurable. *Dictyonema sherrardae mumbilensis* was first described by Rickards and Wright (1997b) from the late Ludlow (*inexpectatus* or *kozlowskii* biozone). The specimens from locality W910 are a little more robust (dorsoventral width of 0.70-0.80 compared with 0.50-0.60 mm) but the lateral width, thecal spacing, dissepimental spacing, and stipe spacing are all very close. The late Ludlow and Přídolí form *D. s. mumbilensis* differs from the early Ludlow form *D. s. sherrardae* largely in having much more closely spaced autothecae. It is almost certainly an evolutionary derivative of *D. s. sherrardae*.

Family ACANTHOGRAPTIDAE Bulman, 1938
Genus ACANTHOGRAPTUS Spencer, 1878

Type species

Acanthograptus granti Spencer, 1878; by original designation.

Acanthograptus aculeatus neureaensis Rickards and Wright, 1997
Fig. 5C

Synonymy

1997b *Acanthograptus aculeatus neureaensis* subsp. nov.; Rickards and Wright, p. 218, fig. 6H.

Material examined

A single stipe fragment, AMF 114638 from locality W910.

Description

The short fragment of stipe has twigs alternating along its length, each twig probably composed of several thecae possibly with bithecae opening near the base of the twigs. The overall width of the stipe is about 1 mm, and twigs on each side are spaced at 14 in 10 mm. Each twig is about 0.50 mm long. The central part of the stipe is 0.20 - 0.40 mm wide and there are slight indications of bundles of the thecal tubes. Autothecal apertural diameter is 0.10 - 0.15 mm.

Remarks

Acanthograptus aculeatus neureaensis was first described from the late Ludlow (*inexpectatus* to *kozlowskii* biozones) of the Barnby Hills Shale at Neurea, south of Wellington, NSW (Rickards and Wright 1997b). It was considered a successor of the Wenlock to early Ludlow type subspecies *D. aculeatus aculeatus* Počta, 1894. This is the first record of the species from the Přídolí.

Order GRAPTOLOIDEA Lapworth, 1873
Family MONOGRAPTIDAE Lapworth, 1873
Genus PRISTIOGRAPTUS Jaekel, 1889

Type species

Pristiograptus frequens Jaekel, 1889; by original designation.

Pristiograptus cf. ***shearsbyi*** Rickards and Wright, 1999
Fig. 5E-F

Synonymy

cf. 1999 *Pristiograptus shearsbyi* sp. nov.; Rickards and Wright, p. 194, figs 3J-P, 11A, B, 13B, E.

Material

AMF 114640, 114633 and 114642, from W910.

Description

The specimens are straight and narrow, with dorsoventral width up to 1.10 mm distally, and 0.40-0.50 mm at the level of the aperture of th1. The sicula reaches half way between the apertures of th1 and th2 and the sicular length is about 1.30 mm. $\Sigma = 1.2$ mm. Thecal overlap is about $^1/_2$ and thecal inclination 10°-30°. Proximal thecal spacing is 13 in 10 mm, falling to 11 in 10 mm more distally. The sicular aperture has a marked dorsal tongue. All the thecae have pristiograptid apertures, and the ventral thecal wall is typically pristiograptid.

Remarks

These specimens are close to the types from the Yass district. Although they look identical, the distal dorsoventral width is a little greater (1.10 mm compared with 0.85 mm) and the thecal spacing is a little higher (13-11 in 10 mm compared with 12-9 in 10 mm). In the type area *P. shearsbyi* ranges from the *praecornutus* Biozone (Ludlow) through to the *transgrediens* Biozone at the top of the Přídolí, whereas with the present material all one can suggest is Přídolí (see dating of the W910 locality). A few other specimens of *Pristiograptus* (AMF 114794-8) occur at W910 with *P.* cf. *shearsbyi*. These are probably referable to *P. dubius* and recall similar specimens from the Přídolí of the Yass district (Rickards and Wright 1999, figs 3G-I) which have a slight dorsal sicular process.

Genus MONOGRAPTUS Geinitz, 1853

Type species

Lomatoceras priodon Bronn, 1835; by original designation.

Monograptus parultimus minutus Rickards, Wright and Pemberton, 1998
Fig. 5D

Synonymy

1998 *Monograptus parultimus minutus* subspecies nov.; Rickards et al., pp. 227-228, figs 3A-G, 4A-E.

Material

AMF 114669, from W910.

Remarks

This specimen differs little from the types of *M. parultimus minutus* from the Willow Glen Formation, Cudgegong district, NSW. The sicula is slightly longer (1.5 mm compared with 1.2 mm) and the thecal spacing slightly less (16-18 in 10 mm compared with 18-20 in 10 mm). Other measurements are very similar, as is the overall appearance, especially the ventrally curved sicula with its dorsal tongue, and the similarity to *M. p. parultimus* Jaeger, 1975. The exact age of the Willow Glen Formation specimens was not known, but they were considered most likely to be early Přídolí, although possibly as old as late Ludlow. This is not in conflict with the Přídolí age suggested for locality W910. *Monograptus p. minutus* must have evolved by diminution in size and proportions from a more robust ancestor, for the late Ludlow has no similarly small pristiograptid-like species. The material from W910 may be part way along this line of evolution, perhaps a little earlier than the Willow Glen Formation specimens, because the dimensions of the latter are a little less robust and the thecal spacing closer still. Even so, the W910 specimens contrast well with the types of *M. p. parultimus*, and are indistinguishable at first examination from the types of *M. p. minutus*.

Monograptus microdon cf. *aksajensis* Koren', 1983
Fig. 5J-L

Synonymy

cf. 1983 *Monograptus microdon aksajensis* subsp. nov.; Koren', pp. 419-420, pl. 50, figs 6-14; text-figs 4 h-q.

Material

Figured specimens AMF 114632, 114634, 114637, and a considerable number of other specimens, especially proximal ends AMF 114798-818; additional material retained in Sedgwick Museum collections (SM X. 358526-33); all from W910.

Description

Rhabdosome up to 35 mm long; proximally with a dorsoventral width of 0.30 mm, and with proximal end markedly narrow and spike-like; by th10 the dorsoventral width is still only 0.70 mm.; distally relatively robust with a dorsoventral width of 1.30-1.40 mm. A very gentle ventral curvature in some specimens, others straight; sicula often imparts a slight dorsal flexure over the first one or two thecae. Proximal thecal spacing 13 in 10 mm, distally 12 in 10 mm. Sicular length 1.00-1.20 mm, its apex reaching the level of the th1 aperture or a little above, sometimes ventrally curved; Σ = 1.20-1.30. All distally. Small hoods visible on some specimens, on the proximal thecal geniculae, but all distal thecae with pronounced genicular hoods and conspicuous thecal excavations, the supragenicular wall being more or less parallel to the rhabdosomal axis. Virgula projects distally for up to 15 mm in some specimens. Sicular aperture with a marked dorsal tongue.

Remarks

This material clearly has some similarity to both *M. m. microdon* and *M. m. aksajensis*. We agree with Koren' (1983) that *M. microdon silesicus* Jaeger, 1959 is best regarded as a junior synonym of the type subspecies. The shape and dimensions of our specimens are close to *M. m. aksajensis* over the first 10 mm, agreeing with Koren's (1983) dimensions for the types from Kazakhstan. However, the distal dorsoventral width is greater (1.30-1.40 mm compared with 0.95 mm). The thecal spacing is the same and can be contrasted with the type subspecies (13-12 in 10 mm compared with 10-8 in 10 mm). Apart from the distal dorsoventral width our specimens are closer to Koren's than to Jaeger's. *Monograptus microdon aksajensis* was recorded by Koren' (1983) from the near the top of the Přídolí, and *M. microdon microdon* by Jaeger (1959) from the latest Ludlow and earliest Devonian.

Monograptus cf. *yassensis* (Rickards and Wright, 1999)
Fig. 5G-I

Synonymy

cf. 1999 *Neocucullograptus? yassensis* sp. nov.; Rickards and Wright, figs 4U-W, 13L, M.

Material

A number of fragmentary specimens from locality W910, including AMF 114636, 114639, 114793, and 114798-819.

Description

The rhabdosome is extremely slender, not exceeding 0.25 mm on the most robust fragments. Thecal spacing is 6-7 in 10 mm, with very low thecal overlap. The prothecal section above the simple hook is extremely narrow, 0.05 mm in the case of proximal thecae, 0.10 mm in more distal thecae. The late protheca, just before the metathecal hook, has a dorsoventral width of 0.10-0.13 mm. The hook is difficult to interpret but seems to be a simple retroversion of the dorsal wall of the theca, the ventral apertural wall lip not contributing to the hook. The dorsoventral width at the level of the hooks is 0.20-0.25 mm so that the hook occupies about half the total width of the rhabdosome.

Remarks

These minuscule specimens are much smaller than any described true neocucullograptids (which have never been recorded from the Přídolí): nevertheless Rickards and Wright (1999) referred similar material from the Yass Přídolí doubtfully to *Neocucullograptus* (see above). This was because there were so few forms with which to compare the Yass materials save the stratigraphically earlier neocucullograptids. Our latest (unpublished) work on the Yass specimens indicates a simple, small hook similar to those in the W910 locality of this paper, hence we here refer the forms to the portmanteau concept of *Monograptus*.

The W910 specimens differ from those from Yass (*parultimus* Biozone) in having a lower thecal spacing (6-7 in 10 mm compared with 7-10 in 10 mm). *Crinitograptus operculatus* (Münch, 1938), described by Rickards and Wright (1999) from the early Přídolí of Yass is a more robust species, has different hooks and a less tapering prothecal section. *Monograptus mitchelli* (Rickards and Wright, 1999) is another, more robust species with a different hook structure and even lower thecal spacing (4.5 in 10 mm).

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[Begin Page: Page 173]

Silurian Biostratigraphy of the Cadia Area, South of

Orange, New South Wales

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Biostratigraphy of the Cadia Area, South of Orange, New South Wales.

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New Silurian fossil discoveries in the vicinity of Cadia Mine indicate ages younger

than shown on recent maps. Limestone, intersected in drill core immediately above an

unconformable contact with Late Ordovician volcanics of the mine sequence, yielded an

early Wenlock conodont fauna including Pterospathodus amorphognathoides, P. procerus and P. rhodesi, together with Kockelella ranuliformis. A diverse shelly fauna of late Wenlock to early Ludlow aspect, dominated by brachiopods, is present in a slumped mudstone on the mine access road. South of the mine, in Rodds Creek valley, Silurian rocks are shown to occur as infaulted slices along the Werribee Fault. Limestone pods in this area contain conodonts (Coryssognathus dubius) indicative of a Ludlow age; a graptolite fauna from nearby siltstones includes Monograptus flemingii warreni, M. flexilis, Monoclimacis flumendosae flumendosae and Cyrtograptus ex. gr. C. rigidus, and is assigned to the lundgreni-testis Biozone (late Wenlock). The youngest graptolite assemblage (Pffdolf) occurs in siltstones, tentatively correlated with the Wallace Shale, exposed in a shallow excavation east of Cadia Mine. This fauna, which includes Dictyonema sherrardae mumbilensis, Acanthograptus aculeatus neureaensis, Pristiograptus shearsbyi, P. cf. P. dubius, Monograptus parultimus minutus, M. microdon aksajensis and M. cf . M. yassensis, is younger than all known graptolite faunas from the nearby Four Mile Creek area, and provides the first Australian record of Monograptus microdon.

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KEY WORDS: Silurian, biostratigraphy, graptolites, conodonts, brachiopods

INTRODUCTION

Cadia Mine, situated 20 km SSW of the city of Orange in the central west of New South Wales (Fig. 1), is a significant producer of gold and copper ore hosted within a Late Ordovician volcanic succession. The source of the mineralising fluids is believed to have been associated with igneous intrusions of latest Ordovician or earliest Silurian age. Overlying Silurian strata are not mineralised and, therefore, have received less attention from geologists, other than in thesis studies and regional mapping projects. Until recently, Silurian sedimentary rocks overlying the mine sequence were assumed to belong to the Cadia Coach Shale, of early-middle Llandovery age (Jenkins 1978), and

[Begin Page: Page 174]

Figure 1 . Locality map covering 8630-N Canowindra 1 :50 000 (NE corner) and Millthorpe 8731-3-S 1:25 000 (SE corner) topographic sheets, prepared from an aerial photograph of the Cadia mine area supplied by Newcrest Mining Ltd, showing positions of palaeontological sample sites C1885, C1890, C1891, W906, W910, and macrofossil locality on mine access road.

[Begin Page: Page 175]

were mapped as such by Krynen et al. (1997). Few, if any, fossil localities were known in the vicinity of the mine to confirm this age determination. Offenberg (1963) in an unpublished thesis, reported a triangulatus graptolite fauna (early-middle Llandovery age) from the upper reaches of Rodds Creek, and a testis graptolite fauna (late Wenlock) from a tributary of Cadiangullong Creek. None of this material has been located for verification, and in particular the early-middle Llandovery age assemblage appears anomalous in the light of our recent discoveries. An alternative interpretation (G.H. Packham, pers. comm.) is that the supposed triangulatus forms are fragments of

Cyrtograptus, similar to those described by Rickards et al. (1995) from strata of Ludlow age in the Quarry Creek area, south of Orange. Bischoff (1986, 1997, 1998) determined conodonts from limestone in core, from a hole drilled by Pacific Copper (the previous leaseholder of the mine site during the 1970s) near Cadia Quarry, as latest Llandovery; he assigned them to the Pterospathodus amorphognathoid.es — P. rhodesi Assemblage Zone (Jeppsson 1997; Bischoff 1998). On the basis of this age, Packham et al. (1999) correlated the Silurian limestone in subcrop at Cadia with units at the top of the Waugoola Group, such as the Glendalough Formation and the Boree Creek Formation.

New palaeontological data derived from localities made known to us by geologists from Newcrest Mining Limited, operator of the Cadia Mine, has enabled us in the current paper to (1) recognise the existence of Silurian rocks where these were previously unknown, and (2) to demonstrate that outcrops mapped as Early Silurian Ashburnia Group on the second edition Bathurst 1 :250 000 Geological Map (Raymond, Pogson et al. 1998) are in fact much younger, some possibly correlative with the Wallace Shale of Pndoli age. It should be noted here that stratigraphic terminology applied to the Silurian strata of the region has not yet stabilised; various schemes have been proposed by Jenkins (1978), and in the Explanatory Notes to the second edition Bathurst geological map (Pogson and Watkins 1998). Our aim in documenting faunas from new fossil localities around Cadia is to increase biostratigraphic precision, allowing more confident correlation with those areas where the stratigraphic succession is well established. It is not the intention of this contribution to revise the geological mapping of exposures in the vicinity of Cadia Mine, as most of the area is held under exploration leasehold; although it has been mapped in considerable detail by company geologists, this information remains confidential.

Added impetus was given to this project by imminent extensions to the minesite infrastructure, which will entail several of the localities studied herein becoming inaccessible. Those in the lower valley of Rodds Creek will shortly be submerged beneath a southern extension of the Cadia Hill tailings storage facility, while the site of drill hole STRC 198 is located adjacent to a planned water holding dam SE of the Cadia Mine. Exploration geologists from Newcrest Ltd facilitated access to these sites and samples, prior to commencement of earthworks associated with these projects (outlined on Fig. 1).

Rickards and Wright studied the graptolite faunas documented herein as part of a larger project being undertaken with Dr Gordon Packham on the Silurian graptolites of the nearby Four Mile Creek area. The limestone samples were processed for conodonts at the Lidcombe laboratory of the NSW Department of Mineral Resources, and their age implications were analysed by Simpson and Percival. The brachiopods were studied by Percival.

Grid references (GR) quoted in the text refer to AMG co-ordinates on the Canowindra 8630-N 1:50 000 and Millthorpe 8731-3-S 1:25 000 topographic sheets, and were determined in the field using a hand-held GPS unit. Locality numbers prefixed by C indicate Geological Survey of NSW microfossil collections (figured conodonts designated MMMC), and those prefixed by W are University of Wollongong localities. Illustrated macrofossils are catalogued either in collections of the Australian Museum, Sydney (prefix AMF), or in the Geological Survey of NSW palaeontology collection (specimens denoted MMF) housed at Lidcombe, NSW.

[Begin Page: Page 176]

GEOLOGICAL CONTEXT OF NEW FOSSIL DISCOVERIES

Recent drilling by Newcrest Mining Limited in the upper reaches of Rodds Creek, about 2.5 km SE of the Cadia Hill mine mill (Fig. 1), intersected limestone 2 m above an unconformity with the Late Ordovician volcanics forming the mine sequence. Limestone chips from the reverse circulation hole STRC 198 were processed using standard acetic acid dissolution techniques, and yielded a diverse earliest Wenlock conodont assemblage (CI 885), further discussed below. The significance of this discovery is that for the first time in the Cadia area, an age-diagnostic Silurian fauna has been accurately located with respect to the Ordovician succession. The age of the latter at Cadia is known to be middle Late Ordovician, specifically late Eastonian (Ea3) (Packham et al. 1999). Elsewhere in the nearby region, in the valley of the Belubula River to the south, the youngest Ordovician unit (Angullong Formation) contains late Late Ordovician graptolites (middle Bolindian, no younger than Bo3) (Jenkins 1978). The stratigraphic break between the top of the Ordovician volcanics and the base of the Silurian limestone in drill hole STRC 198 corresponds to the interval of igneous intrusions (isotopically dated at about 446 Ma - see Packham et al. 1999:8) which are believed responsible for introduction of the mineralisation to the Cadia area, prior to resumption of sedimentation in the Silurian.

Nearby in the valley of Rodds Creek, south of the present Carcoar-Panuara road (Fig. 1), an area adjacent to the Wongalong Fault had previously been mapped as Angullong Formation (formerly Angullong Tuff) by Smith (1966). More recently, the major structural feature through the region has been renamed the Werribee Fault, separating two blocks characterised by different facies of the Middle to Late Ordovician Weemalla Formation (Raymond, Pogson et al. 1998). An isolated limestone pod containing halysitid and favositid corals, which had been mapped as part of the Angullong Tuff by Smith (1966), was reassessed by Jenkins (1978: 122) who identified Haly sites aff. H. amplitubata Lambe (form B) from this locality. Jenkins noted that this species also occurred in the Cobblers Creek Limestone at the base of the Waugoola Group, of late Llandovery age. This limestone pod was sampled for conodonts (locality CI 890) and yielded one element of Coryssognathus dubius; this species has a range from late Llandovery to early Pndoli, but is locally restricted to the Ludlow.

The limestone pod is at the southern end of a fault slice of Silurian sediments within the Weemalla Formation on the Werribee Fault. About 250 m upstream from the limestone, late Wenlock graptolites, correlated with the lundgreni-testis Biozone, are present in black siltstones in the west bank of Rodds Creek (locality W906). The age of this assemblage, discussed below, suggests that the probable Ludlow age inferred for CI 890 is not unrealistic. Another, smaller, limestone pod was sampled for conodonts (GSNSW locality CI 891) in a tributary gully of the main creek, but the small assemblage of fragmentary and poorly preserved elements included no age-diagnostic forms.

Brachiopods and other shelly fauna are preserved in a mudstone on the main Cadia mine access road at GR 687250 6295000. All shells are disarticulated, and many other fossils are fragmentary, indicative of slumping of the horizon into deeper water; sedimentary structures confirm this interpretation. Very rare well-rounded pebbles are present, but the lithology is predominantly a grey to white fine silt to mud lithology, weathering brown. The fossils are scattered throughout the rock, but are occasionally concentrated in parallel layers. Several of the brachiopods found at this site are similar to those previously described from the late Wenlock Panuara Formation of the Spring and Quarry Creek area, west of Orange.

The youngest Silurian strata in the Cadia area have been recognised in a road gravel pit (locality W910), adjacent to the road through the forest east of the mine access road. Here, loose blocks on the quarry floor yielded very rare shelly

[Begin Page: Page 177]

Figure 2. SEM photographs of Silurian conodonts from locality CI 885 (a-v) and CI 890 (w); a, Pa element of Pterospathodus procerus, MMMC 2565; b, Pa element of Pterospathodus rhodesi, MMMC 2566; c, d. Pa and Pb elements of Pterospathodus amorphognathoides, MMMC 2567, 2568; e, f, g. Pa, Pb and Sa elements of Apsidognathus tuberculatus, MMMC 2569, 2570, 2571; h, i, Pa and Sc elements of Distomodus staurognathoides, MMMC 2572, 2573; j, Carniodus carhulus, MMMC 2574; k, Pa element of Kockelella ranuliformis, MMMC 2575; 1, m, Amelia mischa, MMMC 2576, 2577; n, Panderodus unicostatus, MMMC 2578; o, Panderodus recurvatus, MMMC 2579; p, Pseudobelodella sp., MMMC 2580; q, r, Pb and Sa elements of Pseudolonchodina (Aspelundia) borenorensis, MMMC 2581, 2582; s, t, Sa and Sc elements of Oulodus rectangularis, MMMC 2583, 2584; u, Pyrsognathus latus, MMMC 2585; v, Pyrsognathus obliquus, MMMC 2586; w, Sb element of Coryssognathus dubius, MMMC 2587; each scale bar represents 100 microns.

[Begin Page: Page 178]

fossils (brachiopod Skenidioides; indeterminate coral), associated with graptolites of Pfidoli age. This age is younger than that of all known graptolite faunas from the

Four Mile Creek area to the west of Cadia, where rich Llandovery to Ludlow graptolite faunas have been known since the work of Stevens and Packham (1953).

NEW OCCURRENCES OF SILURIAN CONODONTS [AJS and IGP]

Limestone from Newcrest drillhole STRC 198 (locality C1885)

The drilling site, located at GR 686829E 6293 159N, was intended to determine sub-surface geology in the vicinity of a proposed extension of the mine water reservoir. The cuttings were logged by N. Swingler for Newcrest Exploration. After intersecting a feldspathic siltstone from surface to 19 m, followed by 12 m of calcareous arkose, and a further thick succession of feldspathic siltstone, chips of a pink-grey pyritic limestone were recovered from a depth interval of 79-87 m. The lower limit corresponds to a depth 2 m above the contact with lithic volcaniclastic breccia referred to the Ordovician Forest Reefs Volcanics; the intervening 2 m is composed of calcareous grit, according to the well log.

Conodonts extracted from the limestone sample of 2.7 kg (Fig. 2) were identified as: Amelia mischa, Apsidognathus tuberculatus, Carniodus carnulus, Distomodus staurognathoides, Kockelella ranuliformis, Oulodus rectangularis, Panderodus unicostatus, P. recurvatus, Pseudobelodella sp., Pseudolonchodina (Aspelundia) borenorensis (= Oulodus planus borenorensis Bischoff, 1986), a single specimen of Pseudooneotodus tricornis, Pterospathodus amorphognathoides, Pt. procerus, Pt. rhodesi, Pyrsognathus latus and Py. obliquus. Presence of the three species of Pterospathodus places the assemblage within the late Llandovery to early Wenlock amorphognathoides Assemblage Zone. Additionally, elements of Panderodus recurvatus are identical with those attributed to the amorphognathoides Zone by Jeppsson (1997:Fig 7.5). Many of the species recognised from CI 885 also occur in the Quarry Creek Limestone and Boree Creek Formation (Bischoff 1986,1997; Cockle 1999) and correlative units elsewhere in the central west of NSW.

This conodont assemblage also has many species in common with that documented by Bischoff (1986) from drillhole PC402 at Cadia, with two important exceptions. The occurrence of a single broken specimen of Kockelella ranuliformis in CI 885 (Fig. 2k) suggests an age for this sample of earliest Wenlock, rather than late Llandovery as determined by Bischoff (1986) for the limestone intersected in PC402. Although K. ranuliformis is found in great numbers during the Wenlock ranuliformis Zone, its first appearance precedes the base of this zone (Barrick and Klapper 1976). Earliest known occurrences of K. ranuliformis include Llandovery examples from Great Britain (Aldridge 1985) and Greenland (Armstrong 1990). However, K. ranuliformis was never recovered from Llandovery strata in Bischoff 's (1986) extensive documentation of Early Silurian conodont faunas from NSW. Its occurrence with species of Pterospathodus in CI 885, therefore, permits a very narrow age diagnosis of earliest Wenlock, near the close of the amorphognathoides Zone. The presence of Pseudooneotodus tricornis is also in accord with this restricted time interval, although rare examples from the Llandovery celloni Zone are known (Bischoff 1986:Text-fig. 10).

Bischoff (1986:35) favoured an early age within the amorphognathoides Zone (i.e. late Llandovery) for PC402 based on the occurrence of Ozarkodina cadiaensis. This species, however, is poorly known and probably ecologically constrained (Simpson and Talent 1995:142). The late Llandovery age for this species seems to be based on one single occurrence of the species from low in the Boree Creek Formation (sample B5, Bischoff 1986:Table 10). Simpson (1995) pointed out that there are some difficulties with interpreting the position of the lower boundary of the amorphognathoides Zone within the Boree Creek sequence. Ozarkodina cadiaensis has also been recovered from the Lobelia Limestone in the Limestone Creek region of eastern Victoria (Simpson and

[Begin Page: Page 179]

Talent 1995), for which a generalised late Llandovery to Early Wenlock age (celloni to amorphognathoides zones) has been inferred. Absence of Ozarkodina cadiaensis from the fauna of CI 885 could be interpreted as indirect evidence in support of a slightly younger age than that of PC402, although caution would be advised in view of possible ecologic constraints and uncertainties concerning the full range of this taxon.

Limestone pod in Rodds Creek (locality C1890)

It is not clear whether the isolated limestone outcrop at GR 684437E 6288532N, previously recognised by Jenkins (1978) as being of probable late Llandovery age on the basis of a halysitid coral similar to a species from the Cobblers Creek Limestone (see above), is allochthonous or autochthonous. Other macrofossils present, including favositid corals, do not assist with precise age determination. A sample weighing 8.2 kg of this limestone yielded 39 conodont elements, mostly Panderodus, but also including a solitary example of Walliserodus sp., and a single ramiform element of Coryssognathus dubius (Fig. 2w). The latter species implies a probable Ludlow age for the limestone, based on other Eastern Australian occurrences (Link and Druce 1972; Simpson et al. 1993; Simpson and Talent 1995; Cockle 1999; Talent and Mawson 1999), although the species is elsewhere reported to range from late Llandovery to early Pfidoli (Miller and Aldridge 1993). The relative abundance of coniform conodont elements is not usually a feature of Early Silurian faunas. The microfossil assemblage is dominated by abundant smooth ostracodes, whose identity has not been determined.

Limestone pod in Rodds Creek valley (locality C1891)

A separate limestone lens at GR 684354E 6288723N, approximately 300 m NW of the Wenlock graptolite locality W906, is surrounded by siltstones and could be allochthonous. Alternatively, given its recrystallized appearance, it may have been caught up in a faulted zone associated with the main Werribee Fault, and tectonically emplaced. Conodonts recovered from a 7 kg sample of the limestone are fragmentary, making identification tenuous. Most have surface textures suggestive of post depositional fluid movements. The fauna consists of IWalliserodus sp., Panderodus sp., Oulodus sp. and Ozarkodina sp. Some of the fragmentary Sa and Sb elements of Ozarkodina sp. have a basal cavity morphology resembling that of Ozarkodina excavata. It is only possible to infer a very generalised Silurian to Early Devonian age for this fauna.

NEW OCCURRENCES OF SILURIAN BRACHIOPODS AND OTHER MACROFAUNA [IGP]

Fauna identified in the outcrop in the Cadia Mine access road include brachiopods Skenidioides sp., an indeterminate orthoidean, Plectodontal sp., Lissatrypal sp., Atrypoidea cf. A. australis, an indeterminate plectatrypid, Coelospiral sp., Nucleospiral sp., and an indeterminate pentamerid; fragments of phacopid and calymenid? trilobites; graptolites (exceptionally rare); bivalves; ostracodes; crinoid ossicles; bryozoa; an indeterminate solitary rugose coral; and an indeterminate stromatoporoid. Selected representatives of this assemblage are illustrated in Fig. 3. Given the fact that virtually all the fauna at this locality is fragmented or disarticulated, having been preserved in a large-scale mud slump, identifications are necessarily provisional; their confirmation will entail much more extensive collections from the site.

All of the brachiopods are represented by isolated valves. Several genera described by Strusz (1982) from the late Wenlock Walker Volcanics of the Canberra area are probably present at the Cadia Mine access road site, including Skenidioides, Lissatrypal (asAustralina), Coelospiral, and Nucleospiral . Skenidioides is a long-ranging form which also occurs in the road base quarry adjacent to Cadia Road (locality W910, discussed below); there it is associated with graptolites of Pridoli age. It is impossible to say whether

[Begin Page: Page 180]

the solitary specimens known from each locality represent the same, or different, species. A specimen of Plectodonta (Fig. 3m-n herein) is possibly comparable to material described as the new species P. brownae by Rickards and Wright (1997a) from a late Wenlock horizon in the Panuara Formation at nearby Cobblers Creek, 3 km SW of Panuara (Fig. 1); generic attribution of the specimen from the Cadia Mine road site is uncertain due to lack of the dorsal valve, and apparent absence (due to preservation) of hingeline denticulation. Rickards and Wright (1997a) also recorded Lissatrypal sp. at Cobblers Creek, suggesting another potential similarity with the Cadia Mine access road assemblage which has yielded a fragmentary ventral and complete dorsal valve (Fig. 3q-r).
denticulation. Rickards and Wright (1997a) also recorded Lissatrypal sp. at Cobblers Creek, suggesting another potential similarity with the Cadia Mine access road assemblage which has yielded a fragmentary ventral and complete dorsal valve (Fig. 3q-r).

The solitary dorsal valve referred to Atrypoidea cf. A. australis clearly displays dorsomedially-directed spiralia (Fig. 3h) and the characteristic smooth exterior (with closely spaced concentric growth rings) of the lissatrypinids (Fig. 3i). Several fragments of shells showing identical spiralia were recognised in the fauna. Atrypoidea australis, originally described from the Molong Limestone, north of Orange, by Mitchell and Dun (1920), was revised by Copper (1977); the age of the Molong Limestone is early Ludlow {ploeckensis and siluricus Conodont Zones; J.W. Pickett, pers. comm.). Copper (1986:text-fig. 18) showed the range of Atrypoidea extending downwards into the late Wenlock.

Also present in the assemblage are incomplete specimens of graptolites (Fig. 3a-b, c) identified as Monograptus sensu stricto. Although the available material does not permit species to be determined, these suggest an age no older than late Llandovery.

NEW OCCURRENCES OF SILURIAN GRAPTOLITES [RBR and AJW]

Rodds Creek Fauna: Age and Significance

A low-diversity Wenlock graptolite fauna was unexpectedly obtained from the west bank of Rodds Creek at GR 684682E 6288609N. The area which includes the Rodds Creek fossil locality was studied by Smith (1966). The graptolite locality W906 is located in the immediate vicinity of the Werribee Fault (Fig. 1) which separates two masses of Ordovician strata. It was not until the graptolites were collected that the presence of Silurian strata in fault slices was recognised. The occurrence of a Wenlock fauna in beds emplaced along the Werribee Fault places a maximum age on the northern segment of that fault. Fifteen kilometres to the SW, between the villages of Lyndhurst and Woodstock, the same fault offsets Ordovician strata against Canowindra Volcanics; the latter unit is palaeontologically constrained and isotopically dated as of early to middle Wenlock age (Krynen and Pogson 1998).

The assemblage consists of four species of graptolites, with the only associated fossils being sponge spicules (Fig. 4H). The fauna comprises: Monograptus flemingii

Figure 3 (facing). Silurian macrofossils from minesite access road locality; a, b, Monograptus sp., counterparts MMF 36716a-b; c, Monograptus sp., MMF 36683; d, free cheek of calymenid trilobite, MMF 36676b;

e, lateral fragment of cephalon of phacopid trilobite, showing large schizochroal eye (damaged), MMF 36708a;

f, Nucleospira? sp., exfoliated internal mould of ventral valve, MMF 36663a; g, Nucleospiral sp, posterior fragment of ventral valve, MMF 36675; h, i, Atrypoidea cf. A. australis, composite internal mould of dorsal valve showing dorsomedially-directed spiralia, and corresponding external mould, MMF 36684a-b; j, indeterminate orthoidean dorsal valve internal mould, MMF 36715; k, Coelospiral sp., ventral valve external, MMF 36677a; I, indeterminate rhynchonellid, dorsal valve exhibiting very weak median septum, MMF 36669a; m. n, Plectodonta? sp., external and internal moulds of ventral valve, MMF 36701a-b; o, Skenidioides sp., ventral valve internal mould, MMF 36666a; p, indeterminate pentameride, internal mould of dorsal valve displaying parallel discrete brachial plates, MMF 36697; q, r, Lissatrypal sp., posterior fragment of ventral valve internal mould, MMF 36662a, and internal mould of dorsal valve, MMF 36712; s, external mould of indeterminate plectatrypid, showing strong growth lamellae, MMF 367 1 1 ; t, cross section of crinoid ossicle, MMF 36694. Magnification of all specimens x4, except for j, 1, r all x3.

[Begin Page: Page 181]

[Begin Page: Page 182]

Salter, 1852 warreni Burns and Rickards, 1993; Monograptus flexilis Wood, 1900 s. L; Monoclimacis flumendosae flumendosae (Gortani, 1922); and Cyrtograptus ex gr. rigidus Tullberg, 1883.

Two species, Cyrtograptus ex. gr. rigidus (Fig. 4H) andM. flexilis s. 1. (Fig. 4C), are each represented in this fauna by only one specimen (plus counterpart). Monograptus flemingii warreni is known from five specimens (Figs 4A-B), and Monoclimacis f. flumendosae (Figs 4D-G) is represented by about one hundred specimens. The last, a cosmopolitan species, closely resembles material from various parts of the world, and is especially well preserved in our collection, showing (for example) the base of the interthecal septum very clearly as a thickened black rod (Figs 4D-G). Without a definite cladium and more specimens, the Cyrtograptus is difficult to identify to species, but it does seem to be too robust for C. ellesae and C. hamatus; however, the proximal regions of some late Wenlock cyrtograptids (except for C. lundgreni and C. pseudolundgreni) are poorly known so our specimen may be referable to one of these forms. A peculiar feature of the assemblage is the absence of Pristiograptus dubius (Suess, 1851), normally a common species in Wenlock assemblages above the middle riccartonensis Biozone (though sometimes uncommon in the lundgreni-testis Biozone).

Monograptus f warreni was recorded from Quarry Creek by Rickards et al. (1995); its full range is probably not yet established, but available records suggest roughly the lundgreni-testis Biozone. Monograptus flexilis has a longer range, appearing in the rigidus Biozone and ranging up into the lower parts of the lundgreni-testis Biozone. Monoclimacis f flumendosae ranges from the upper part of the riccartonensis Biozone through most of the lundgreni-testis Biozone. From these three species, the inferred age is the lundgreni-testis Biozone, the penultimate Wenlock zone. However, Cyrtograptus ex. gr. rigidus does not range up into the lundgreni-testis Biozone, being typical of the rigidus to ellesae biozones; the single specimen from Rodds Creek may have the beginnings of a cladium on th5 (Fig. 4H) which suggests a form close to C. rigidus s.s. The best age that can be inferred for the fauna is middle to late Wenlock, most probably in the early part of the lundgreni-testis Biozone. It should be noted that the ranges of Silurian graptolites occurring in the Spring-Quarry Creek, Four Mile Creek and Cheesemans Creek sequences in the Orange region are not fully established, so that this age assignment, based on non- Australian data, may be inaccurate.

W910 Fauna: Age and Significance

This fauna was collected from bulldozed blocks in a small quarry for road gravel (GR 688584E 6294138N) on the E side of Cadia Road, between the mine access turnoff and the Panuara-Carcoar Road (Fig. 1). Exposures in the vicinity of the gravel pit are poor and deeply weathered, with quarried blocks providing temporary exposures. Graptolites were extracted from laminated lithologies and fragmental brachiopods from brecciated blocks.

The assemblage is: Dictyonema sherrardae mumbilensis Rickards and Wright, 1997; Acanthograptus aculeatus neureaensis Rickards and Wright, 1997; Pristiograptus shearsbyi Rickards and Wright, 1999; Pristiograptus cf. dubius (Suess, 1851); Monograptus par ultimus minutus Rickards et al., 1998; Monograptus microdon aksajensis Koren', 1983; and Monograptus cf. yassensis (Rickards and Wright, 1999). The two dendroids have been recorded previously only from the late Ludlow (inexpectatus to kozlowskii biozones) of the Barnby Hills Shale (Rickards and Wright 1997b). P. shearsbyi has been recorded from the late Ludlow (praecornutus Biozone) into the late Pfidolf (Rickards and Wright 1999:Fig 2). The only previous record of

M. parultimus minutus is from a monotypic assemblage in the Willow Glen Formation of the Cudgegong district, NSW, which Rickards et al. (1998) considered probably of Pfidolf age; however, we have identified this subspecies in collections from Bungonia with Bohemograptus bohemicus tenuis, from what are taken to be late

[Begin Page: Page 183]

Figure 4. A-H, Wenlock graptolites from locality W906. A-B, Monograptus flemingii warreni Burns and Rickards, 1993, respectively AMF 114862, AMF 114863, proximal and distal parts, the latter showing lateral apertural processes. C, Monograptus flexilis Wood, AMF 114866, a poorly preserved specimen lacking the extreme proximal end. D-G, Monoclimacis flumendosae flumendosae (Gortani), respectively two proximal ends AMF 114861, AMF 114864, and two distal fragments AMF 114860,AMF 114865, the last showing the base of the interthecal septum particularly well. H, Cyrtograptus ex gr. rigidus Tullberg, AMF 1 14867. Dashed lines in this figure indicate positions of overlying sponge spicules. Scale bars 1 mm, scale approximately 10.

Ludlow beds. Nevertheless, the last two taxa strongly suggest a Pfidoli age. M. yassensis was recorded from the parultimus Biozone of the Yass district by Rickards and Wright (1999). The crucial species in this list is probably M. microdon R. Richter, 1875, which was recorded by Jaeger (1959) from strata now known to be late Pfidoli; M. microdon aksajensis is latest Pfidoli. The specimens from locality W910 are closest to Koren's subspecies but may be intermediate between M. m. microdon and M. m. aksajensis, or even ancestral to them.

There is, therefore, no precise dating within the Pfidoli for the W910 assemblage, some elements of the fauna suggesting early Pfidoli, others late Pfidoli. Assignment to the late Ludlow would, however, be highly improbable and it seems more reasonable to extend the ranges of the two dendroids in the assemblage from the late Ludlow into the Pfidoli. Monograptus p. minutus is an enigmatic form, the precise age of which is not yet known, other than being Ludlow or Pfidoli; further, its relationship to M. p. parultimus is not known. The discovery of M. microdon Reinhardt Richter, 1875 in Australia is significant: previously it was known only from central Europe, and its subspecies M. m. aksajensis only from Kazakhstan. The occurrence of the latter at W910 does suggest a later rather than earlier Pfidoli age, without being unequivocal. However, the most striking record is that of M. cf. yassensis. These tiny graptolites are very difficult to see in the field, and the present

[Begin Page: Page 184]

Figure 5. A-L, Pffdoli graptolites from locality W910; A, B, Dictyonema sherrardae mumbilensis Rickards and Wright, respectively AMF 114795 and 114796; C, Acanthograptus aculeatus neureaensis Rickards and Wright, AMF 1 14638; D, Monograptus parultimus minutus Rickards et al., AMF 1 14669; E, F, Pristiograptus shearsbyi Rickards and Wright, respectively AMF 1 14640 and 1 14633; G-I, Monograptus cf. yassensis Rickards and Wright, respectively AMF 1 14636, 1 14793 and 1 14639; J-L, Monograptus microdon cf. aksajensis Koren', respectively AMF 114632, 114637, and 114634; scale bars 1 mm.

[Begin Page: Page 185]

collection was only discovered during microscopic examination of rock slabs; our original collections of such tiny forms came from the early Pfidoli of the Yass district (Rickards and Wright 1999). The generic attribution of this species and M. mitchelli (Rickards and Wright, 1999) is very difficult. They seem not to be related to Crinitograptus or Neocucullograptus and yet there are no other small graptolites in the late Ludlow or Pfidoli; both genera are much more robust than M. yassensis.

The W910 locality is unusual for Silurian graptolitic rocks in NSW in that the dendroid graptolites are extensively fragmented, although the preservation of the fragments themselves is quite good, being in part three dimensional. The monograptids are current-oriented and this, inferred to indicate a more turbulent mode of deposition, would account for the fragmented nature of the dendroids.

SYSTEMATIC PALAEONTOLOGY [RBR and AJW]

We have restricted the systematics below to the Pfidoli fauna from W910. The Wenlock assemblage from Rodds Creek (W906), while stratigraphically critical, provides little new palaeontological information. Specimens are catalogued in the palaeontological collections of the Australian Museum, Sydney (prefix AMF).

Class GRAPTOLITHINA Bronn, 1846

Order DENDROIDEA Nicholson, 1872

Family DENDROGRAPTIDAE Roemer in Freeh, 1897

Genus DICTYONEMA Hall, 1851

Type Species

Gorgonia retiformis J. Hall, 1843; by subsequent designation of Miller (1889).

Dictyonema sherrardae mumbilensis Rickards and Wright, 1 997

Fig. 5A-B

Synonymy

1997b Dictyonema sherrardae mumbilensis subsp. no v.; Rickards and Wright, pp. 215-216, fig. 6D.

Description

Dictyonema with aperturally isolated autothecal apertures in which the dorsal process extends as a small plate; autothecal spacing 25+ in 10 mm; dorsoventral width 0.70-80 mm; lateral stipe width 0.20 mm; stipe spacing approximately 8 in 10 mm; dissepimental spacing about 12 in 10 mm.

Material

Several fragmentary specimens, AMF 114795-6 from locality W910.

Remarks

Although available specimens are very fragmentary, the diagnostic features of the species are recognisable and measurable. Dictyonema sherrardae mumbilensis was first described by Rickards and Wright (1997b) from the late Ludlow (inexpectatus or kozlowskii biozone). The specimens from locality W910 are a little more robust (dorsoventral width of 0.70-0.80 compared with 0.50-0.60 mm) but the lateral width, thecal spacing, dissepimental spacing, and stipe spacing are all very close. The late Ludlow and Pfidoli form D. s. mumbilensis differs from the early Ludlow form D. s. sherrardae

[Begin Page: Page 186]

largely in having much more closely spaced autothecae. It is almost certainly an evolutionary derivative of D. s. sherrardae.

Family ACANTHOGRAPTIDAE Bulman, 1938

Genus ACANTHOGRAPTUS Spencer, 1878

Type species

Acanthograptus granti Spencer, 1878; by original designation.

Acanthograptus aculeatus neureaensis Rickards and Wright, 1997

Fig. 5C

Synonymy

1997b Acanthograptus aculeatus neureaensis subsp. no v.; Rickards and Wright, p. 218, fig. 6H.

Material examined

A single stipe fragment, AMF 114638 from locality W910.

Description

The short fragment of stipe has twigs alternating along its length, each twig probably composed of several thecae possibly with bithecae opening near the base of the twigs. The overall width of the stipe is about 1 mm, and twigs on each side are spaced at 14 in 10 mm. Each twig is about 0.50 mm long. The central part of the stipe is 0.20 - 0.40 mm wide and there are slight indications of bundles of the thecal tubes. Autothecal apertural diameter is 0.10 - 0.15 mm.

Remarks

Acanthograptus aculeatus neureaensis was first described from the late Ludlow (inexpectatus to kozlowskii biozones) of the Barnby Hills Shale at Neurea, south of Wellington, NSW (Rickards and Wright 1997b). It was considered a successor of the Wenlock to early Ludlow type subspecies D. aculeatus aculeatus Pocta, 1894. This is the first record of the species from the Pffdoli.

Order GRAPTOLOIDEA Lapworth, 1873

Family MONOGRAPTIDAE Lapworth, 1873

Genus PRISTIOGRAPTUS Jaekel, 1889

Type species

Pristiograptus frequens Jaekel, 1889; by original designation.

Pristiograptus cf. shearsbyi Rickards and Wright, 1999

Fig. 5E-F

Synonymy

cf. 1 999 Pristiograptus shearsbyi sp. nov.; Rickards and Wright, p. 194, figs 3J-

P, 11 A, B, 13B, E.

Material

AMF 1 14640, 1 14633 and 1 14642, from W910.

[Begin Page: Page 187]

Description

The specimens are straight and narrow, with dorsoventral width up to 1.10 mm distally, and 0.40-0.50 mm at the level of the aperture of th 1 . The sicula reaches half way between the apertures of thl and th2 and the sicular length is about 1.30 mm. X = 1.2 mm. Thecal overlap is about 7 2 and thecal inclination 10°-30°. Proximal thecal spacing is 13 in 10 mm, falling to 11 in 10 mm more distally. The sicular aperture has a marked dorsal tongue. All the thecae have pristiograptid apertures, and the ventral thecal wall is typically pristiograptid.

Remarks

These specimens are close to the types from the Yass district. Although they look identical, the distal dorsoventral width is a little greater (1.10 mm compared with 0.85 mm) and the thecal spacing is a little higher (13-11 in 10 mm compared with 12-9 in 10 mm). In the type area P. shearsbyi ranges from the praecornutus Biozone (Ludlow) through to the transgrediens Biozone at the top of the Pridoli, whereas with the present material all one can suggest is Pridoli (see dating of the W910 locality). A few other specimens of Pristiograptus (AMF 114794-8) occur at W910 with P. cf. shearsbyi. These are probably referable to P. dubius and recall similar specimens from the Pfidoli of the Yass district (Rickards and Wright 1999, figs 3G-I) which have a slight dorsal sicular process.

Genus MONOGRAPTUS Geinitz, 1853

Type species

Lomatoceras priodon Bronn, 1835; by original designation.

Monograptus parultimus minutus Rickards, Wright and Pemberton, 1998

Fig. 5D

Synonymy

1998 Monograptus parultimus minutus subspecies nov.; Rickards et al., pp. 227-228, figs 3A-G, 4A-E.

Material

AMF 114669, from W910.

Remarks

This specimen differs little from the types of M. parultimus minutus from the Willow Glen Formation, Cudgegong district, NSW. The sicula is slightly longer (1.5 mm compared with 1.2 mm) and the thecal spacing slightly less (16-18 in 10 mm compared with 18-20 in 10 mm). Other measurements are very similar, as is the overall appearance, especially the ventrally curved sicula with its dorsal tongue, and the similarity to M. p. parultimus Jaeger, 1975. The exact age of the Willow Glen Formation specimens was not known, but they were considered most likely to be early Pf idoli, although possibly as old as late Ludlow. This is not in conflict with the Pridoli age suggested for locality W910. Monograptus p. minutus must have evolved by diminution in size and proportions from a more robust ancestor, for the late Ludlow has no similarly small pristiograptid-like species. The material from W910 may be part way along this line of evolution, perhaps a little earlier than the Willow Glen Formation specimens, because the dimensions of the latter are a little less robust and the thecal spacing closer still. Even so, the W910 specimens contrast well with the types of M. p. parultimus, and are indistinguishable at first examination from the types of M. p. minutus.

[Begin Page: Page 188]

Monograptus microdon cf. aksajensis Koren', 1983

Fig. 5J-L

Synonymy

cf. 1983 Monograptus microdon aksajensis subsp. nov.; Koren', pp. 419-420, pi. 50, figs 6-14; text-figs 4 h-q.

Material

Figured specimens AMF 114632, 114634, 114637, and a considerable number of other specimens, especially proximal ends AMF 114798-818; additional material retained in Sedgwick Museum collections (SM X. 358526-33); all from W910.

Description

Rhabdosome up to 35 mm long; proximally with a dorsoventral width of 0.30 mm, and with proximal end markedly narrow and spike-like; by thlO the dorsoventral width is still only 0.70 mm.; distally relatively robust with a dorsoventral width of 1.30-1.40 mm. A very gentle ventral curvature in some specimens, others straight; sicula often imparts a slight dorsal flexure over the first one or two thecae. Proximal thecal spacing 13 in 10 mm, distally 12 in 10 mm. Sicular length 1.00-1.20 mm, its apex reaching the level of the thl aperture or a little above, sometimes ventrally curved; X = 1.20-1.30. All distally. Small hoods visible on some specimens, on the proximal thecal geniculae, but all distal thecae with pronounced genicular hoods and conspicuous thecal excavations, the supragenicular wall being more or less parallel to the rhabdosomal axis. Virgula projects distally for up to 15 mm in some specimens. Sicular aperture with a marked dorsal tongue.

Remarks

This material clearly has some similarity to both M. m. microdon and M. m. aksajensis. We agree with Koren' (1983) that M. microdon silesicus Jaeger, 1959 is best regarded as a junior synonym of the type subspecies. The shape and dimensions of our specimens are close to M. m. aksajensis over the first 10 mm, agreeing with Koren's (1983) dimensions for the types from Kazakhstan. However, the distal dorsoventral width is greater (1.30-1.40 mm compared with 0.95 mm). The thecal spacing is the same and can be contrasted with the type subspecies (13-12 in 10 mm compared with 10-8 in 10 mm). Apart from the distal dorsoventral width our specimens are closer to Koren's than to Jaeger's. Monograptus microdon aksajensis was recorded by Koren' (1983) from the near the top of the Pfidoli, and M. microdon microdon by Jaeger (1959) from the latest Ludlow and earliest Devonian.

Monograptus cf. yassensis (Rickards and Wright, 1999)

Fig. 5G-I

Synonymy

cf. 1999 Neocucullograptus? yassensis sp. nov.; Rickards and Wright, figs 4U-

W. 13L, M.

Material

A number of fragmentary specimens from locality W9 1 0, including AMF 1 14636, 114639, 114793, and 114798-819.

Description

The rhabdosome is extremely slender, not exceeding 0.25 mm on the most robust fragments. Thecal spacing is 6-7 in 10 mm, with very low thecal overlap. The prothecal section above the simple hook is extremely narrow, 0.05 mm in the case of proximal thecae, 0. 10 mm in more distal thecae. The late protheca, just before the metathecal hook,

[Begin Page: Page 189]

has a dorsoventral width of 0.10-0.13 mm. The hook is difficult to interpret but seems to be a simple retroversion of the dorsal wall of the theca, the ventral apertural wall lip not contributing to the hook. The dorsoventral width at the level of the hooks is 0.20-0.25 mm so that the hook occupies about half the total width of the rhabdosome.

Remarks

These minuscule specimens are much smaller than any described true neocucullograptids (which have never been recorded from the Pfidoli): nevertheless Rickards and Wright (1999) referred similar material from the Yass Pfidoli doubtfully to Neocucullograptus (see above). This was because there were so few forms with which to compare the Yass materials save the stratigraphically earlier neocucullograptids. Our latest (unpublished) work on the Yass specimens indicates a simple, small hook similar to those in the W910 locality of this paper, hence we here refer the forms to the portmanteau concept of Monograptus.

The W910 specimens differ from those from Yass {parultimus Biozone) in having a lower thecal spacing (6-7 in 10 mm compared with 7-10 in 10 mm). Crinitograptus operculatus (Munch, 1938), described by Rickards and Wright (1999) from the early Pfidoli of Yass is a more robust species, has different hooks and a less tapering prothecal section. Monograptus mitchelli (Rickards and Wright, 1999) is another, more robust species with a different hook structure and even lower thecal spacing (4.5 in 10 mm).

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